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Henderson

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(54) **FLOATING SOLAR ENERGY CONVERSION AND STORAGE APPARATUS**

(76) Inventor: **Richard L. Henderson**, Portland, OR (US)

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(51) **Int. Cl.**
F03G 6/00 (2006.01)
B60L 8/00 (2006.01)
B60K 16/00 (2006.01)

(52) **U.S. Cl.** **60/641.9**; 60/641.8

(58) **Field of Classification Search** 60/398, 60/641.1, 641.6, 641.7, 655
See application file for complete search history.

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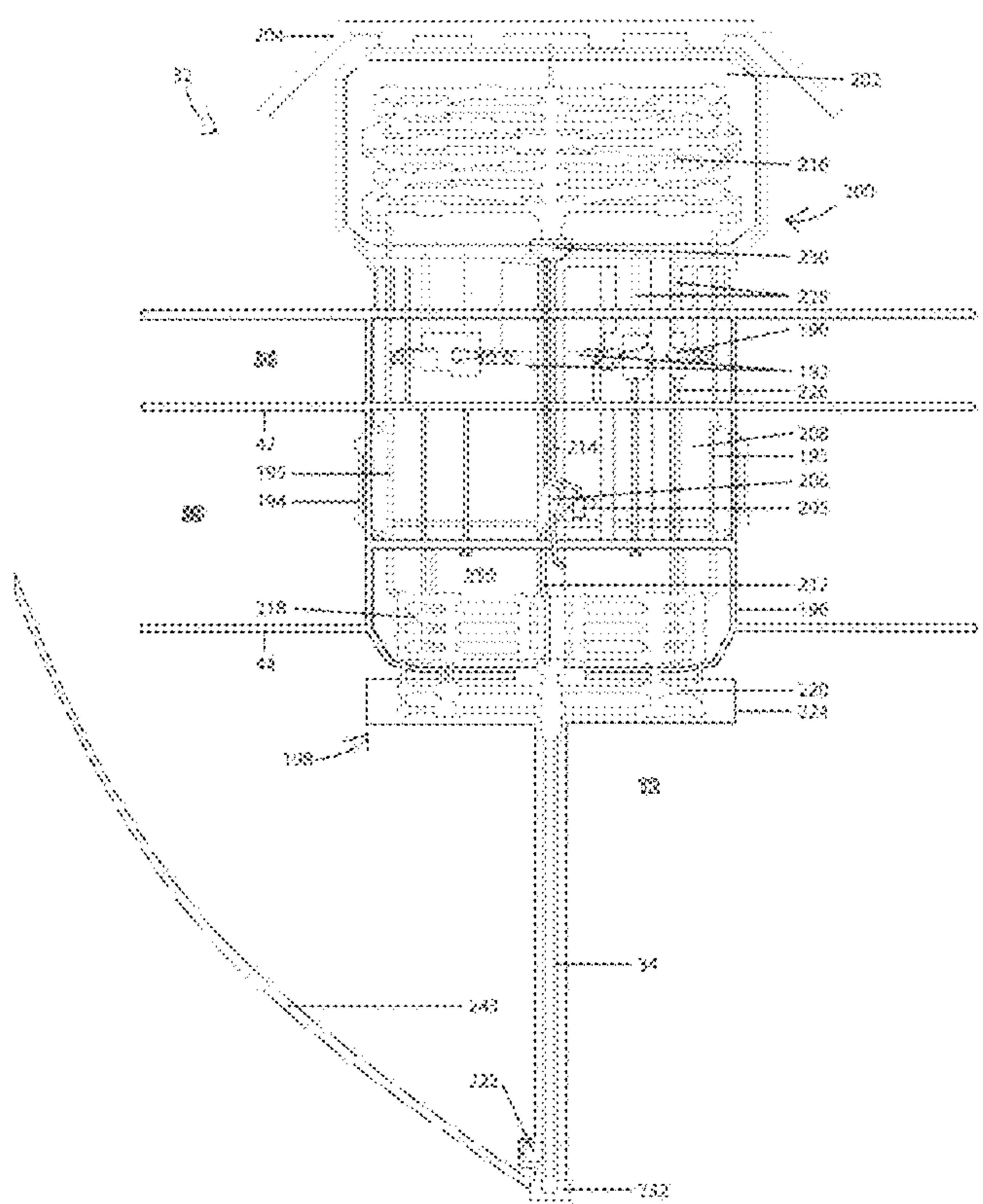
(57) **ABSTRACT**

A solar energy conversion and storage apparatus floats on a body of water and confines and stores a large quantity of solar-heated water for producing electricity with a closed-cycle heat engine. An expansive horizontal structure parallel to the surface of the water confines one or more horizontal layers of water, a distributed array of heat transfer structures gathers solar energy and imparts it to the confined water, and one or more heat engines produce electricity utilizing the temperature differential between the confined water and ambient water. The heat transfer structures can be configured to transfer solar energy to the confined water using a convective process; and some or all of the heat transfer structures can be configured to transfer solar energy to the stored water using a distillation process that optionally produces distilled water as a by-product.

16 Claims, 11 Drawing Sheets



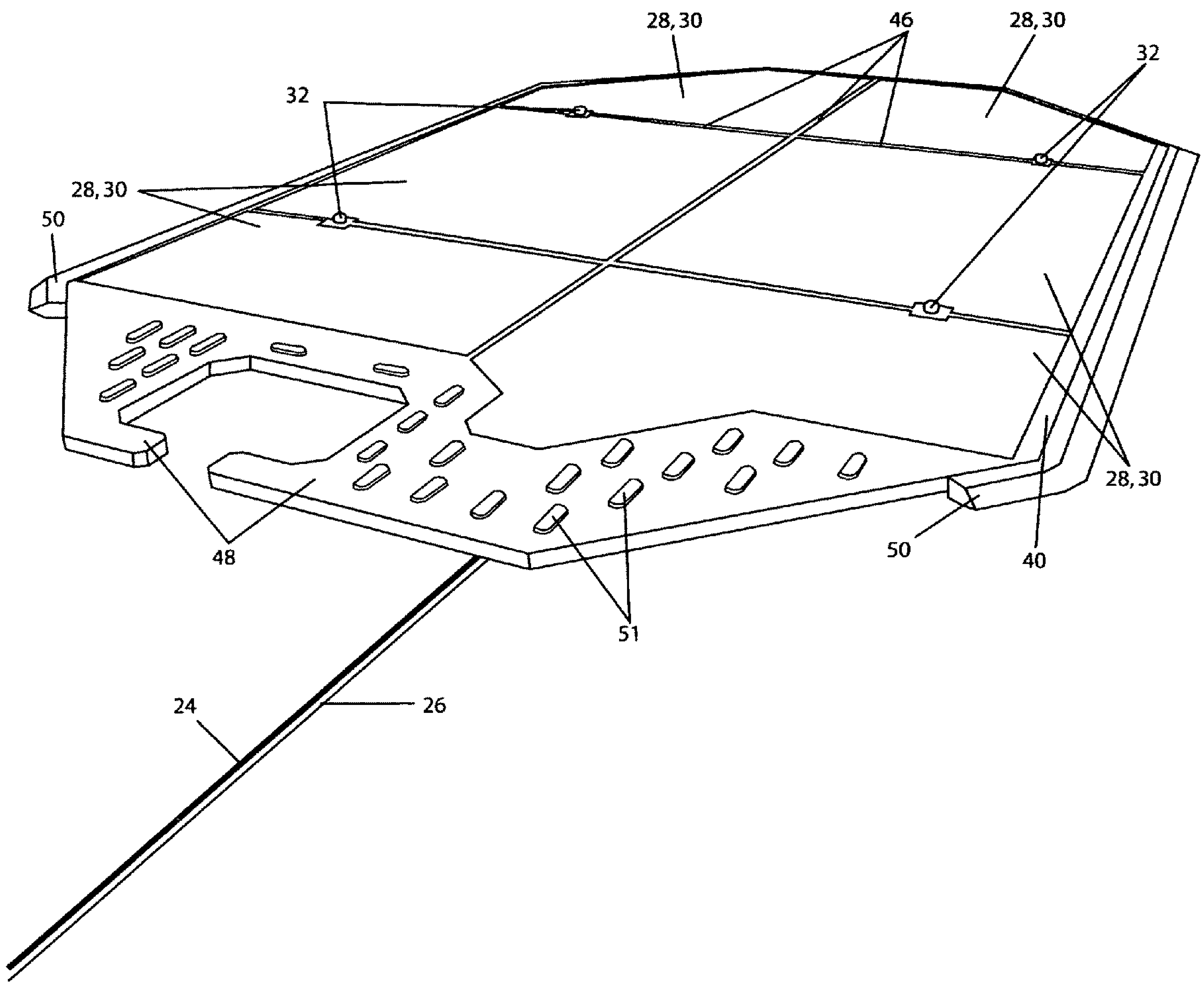


Fig. 1A

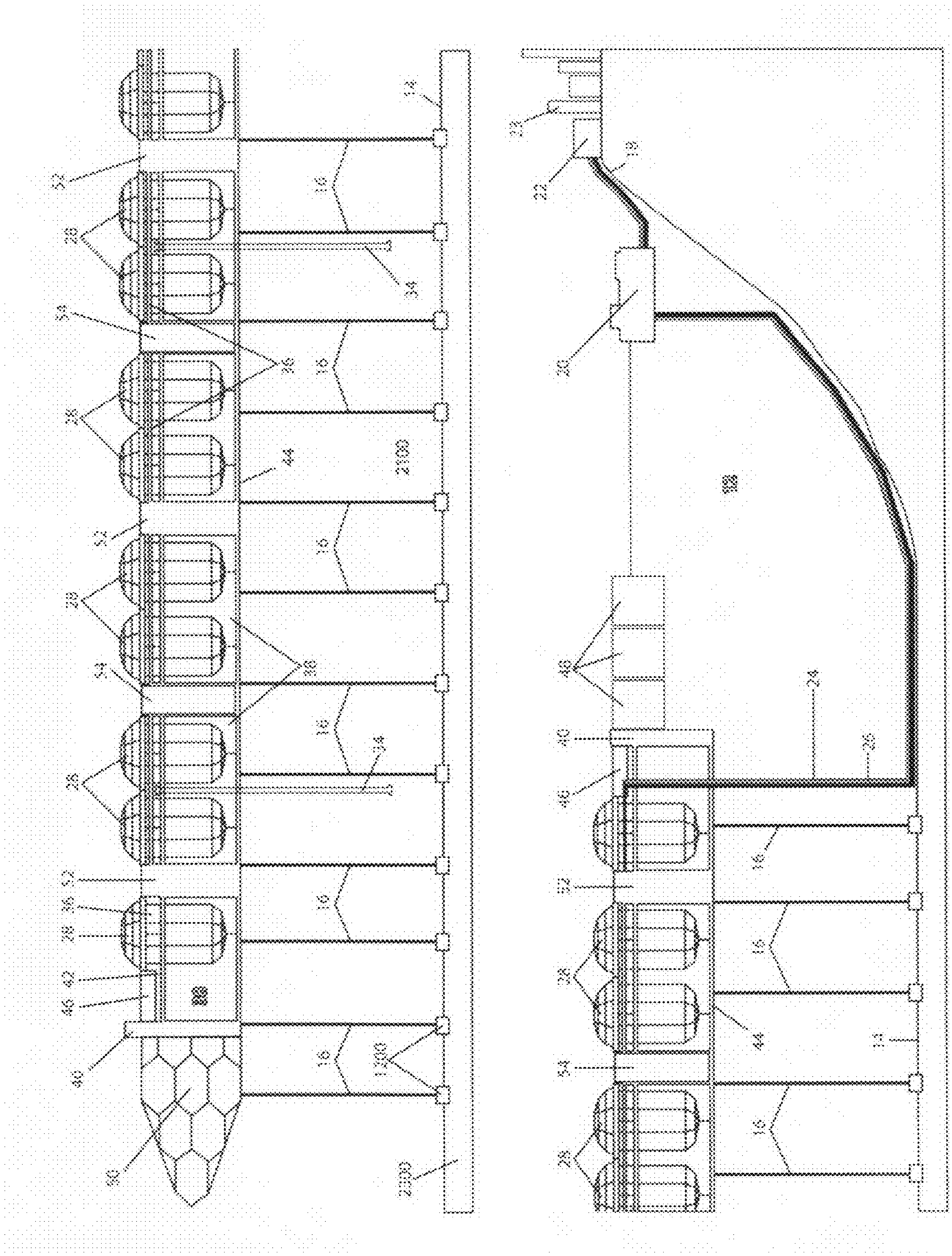


Fig. 1B

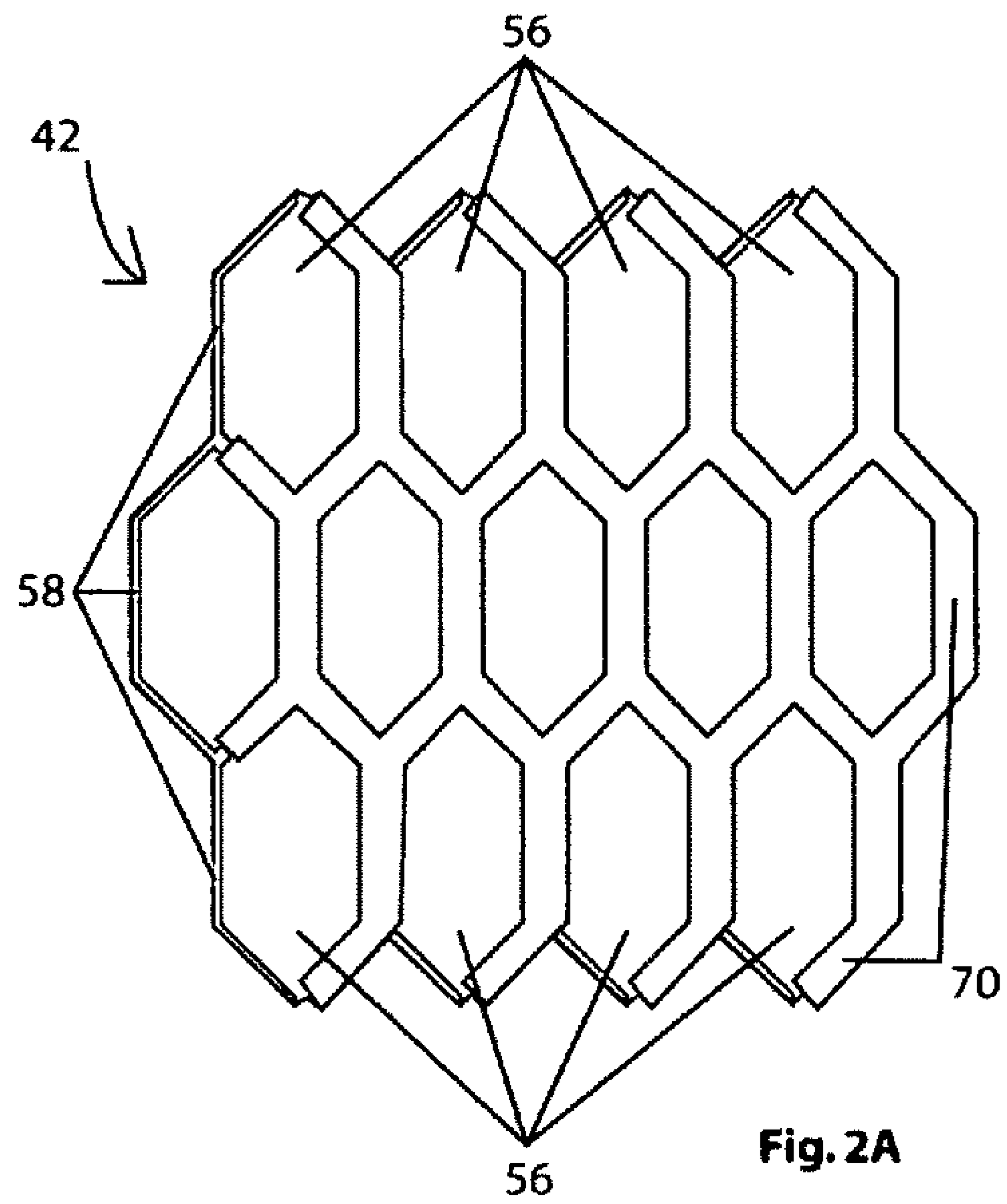


Fig. 2A

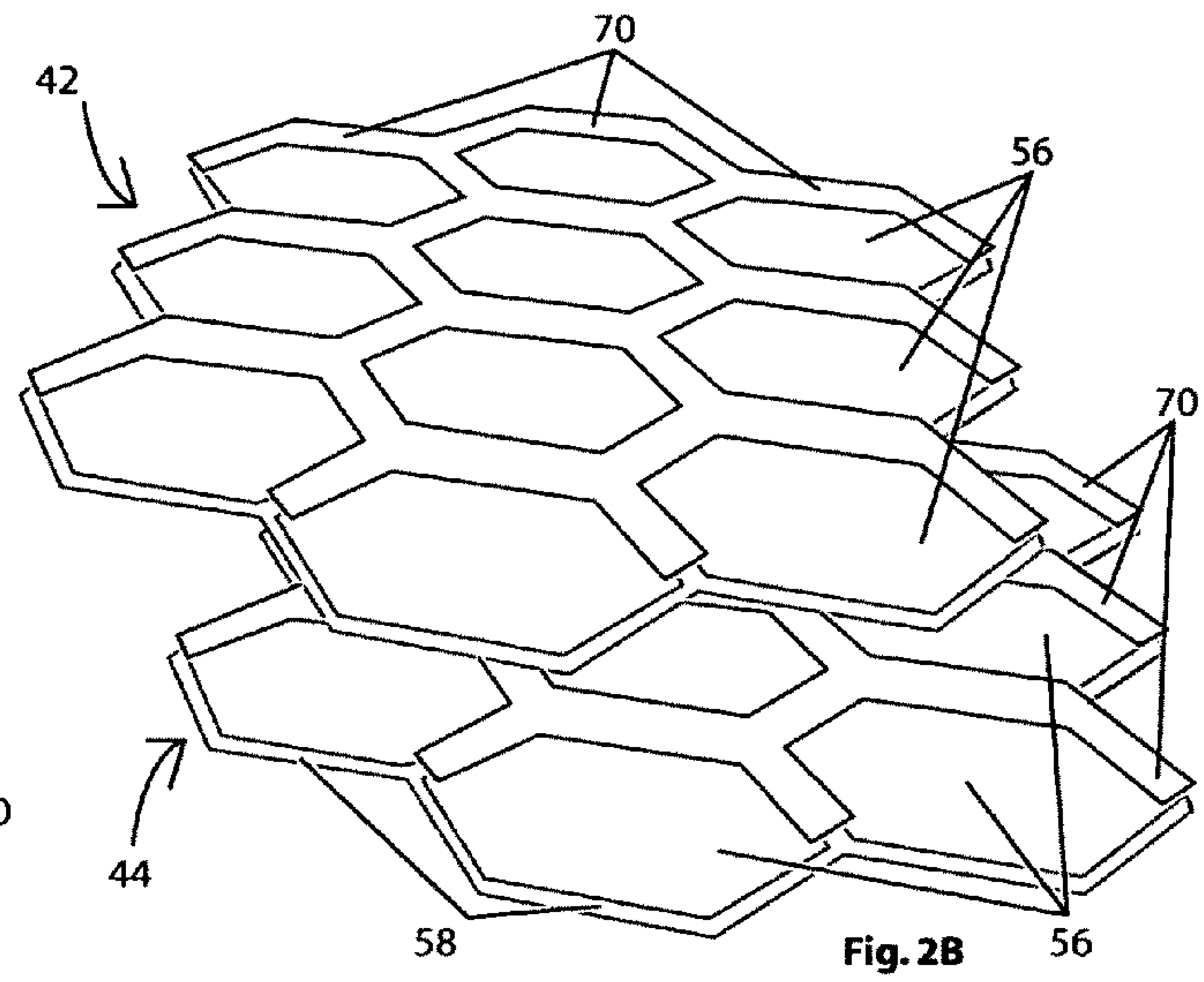


Fig. 2B

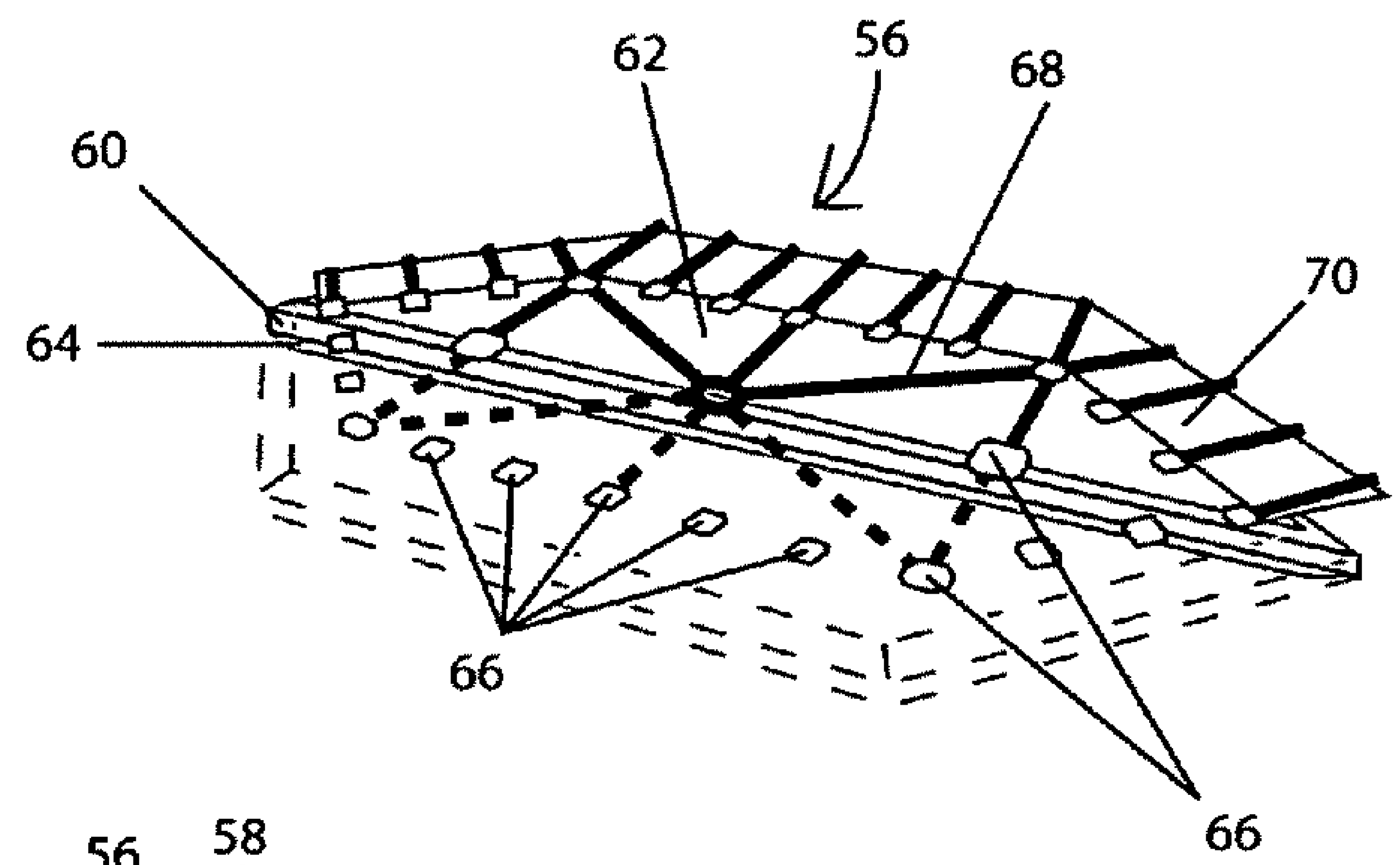


Fig. 2C

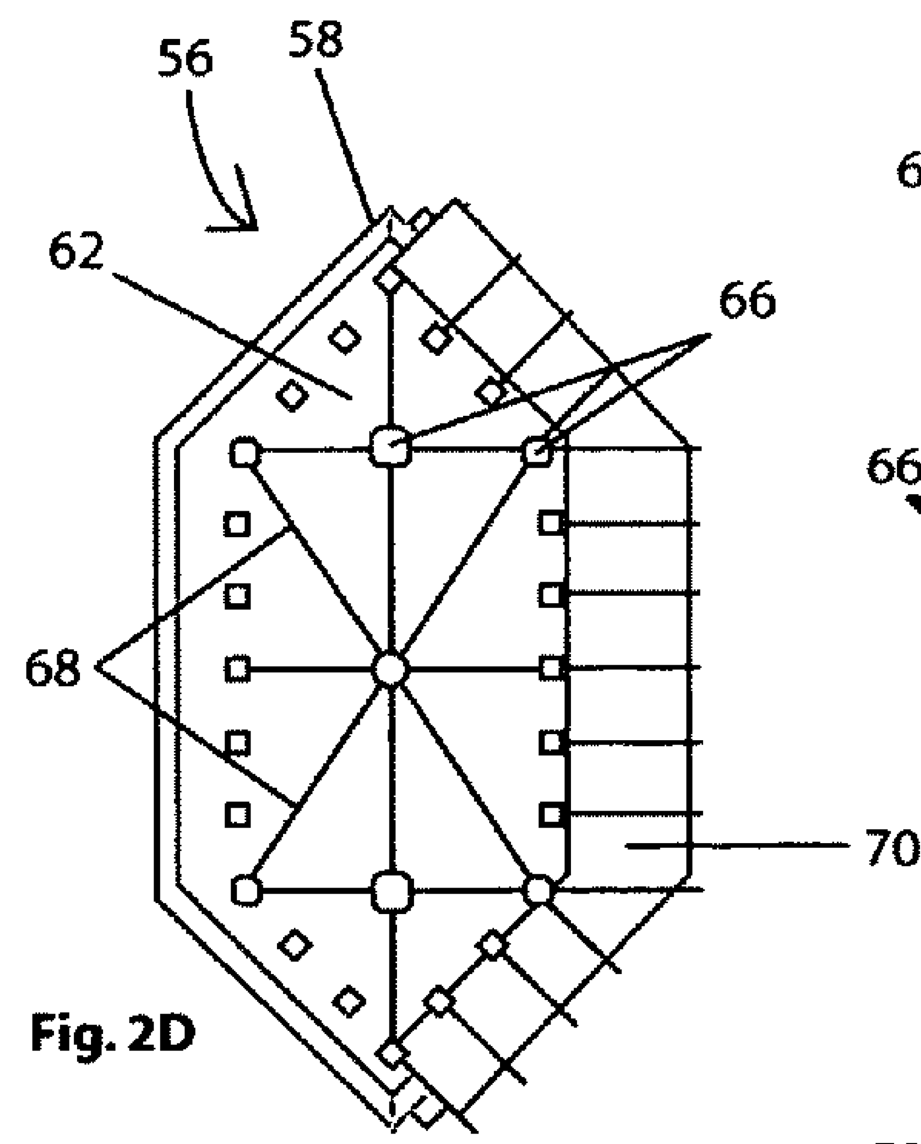


Fig. 2D

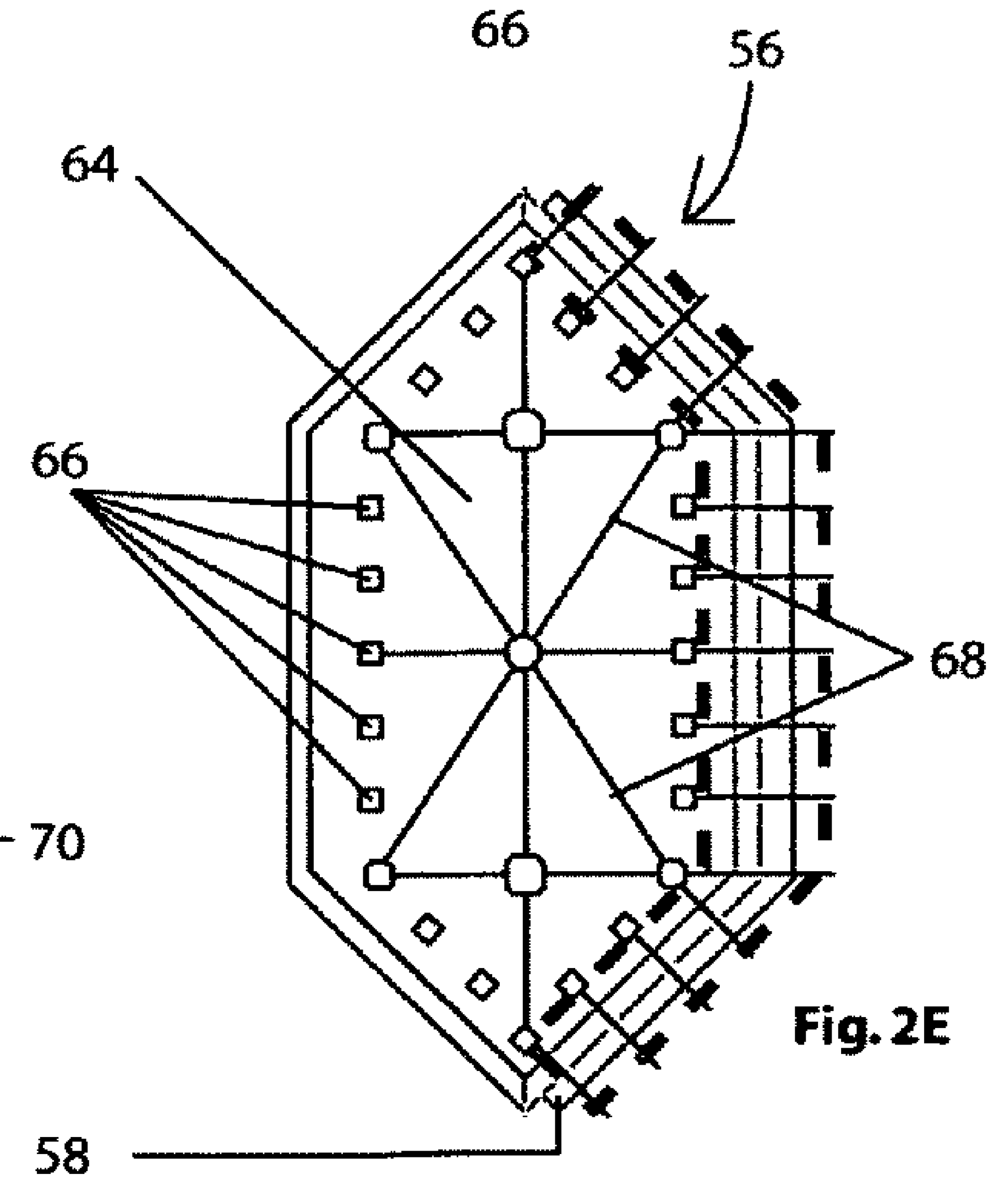


Fig. 2E

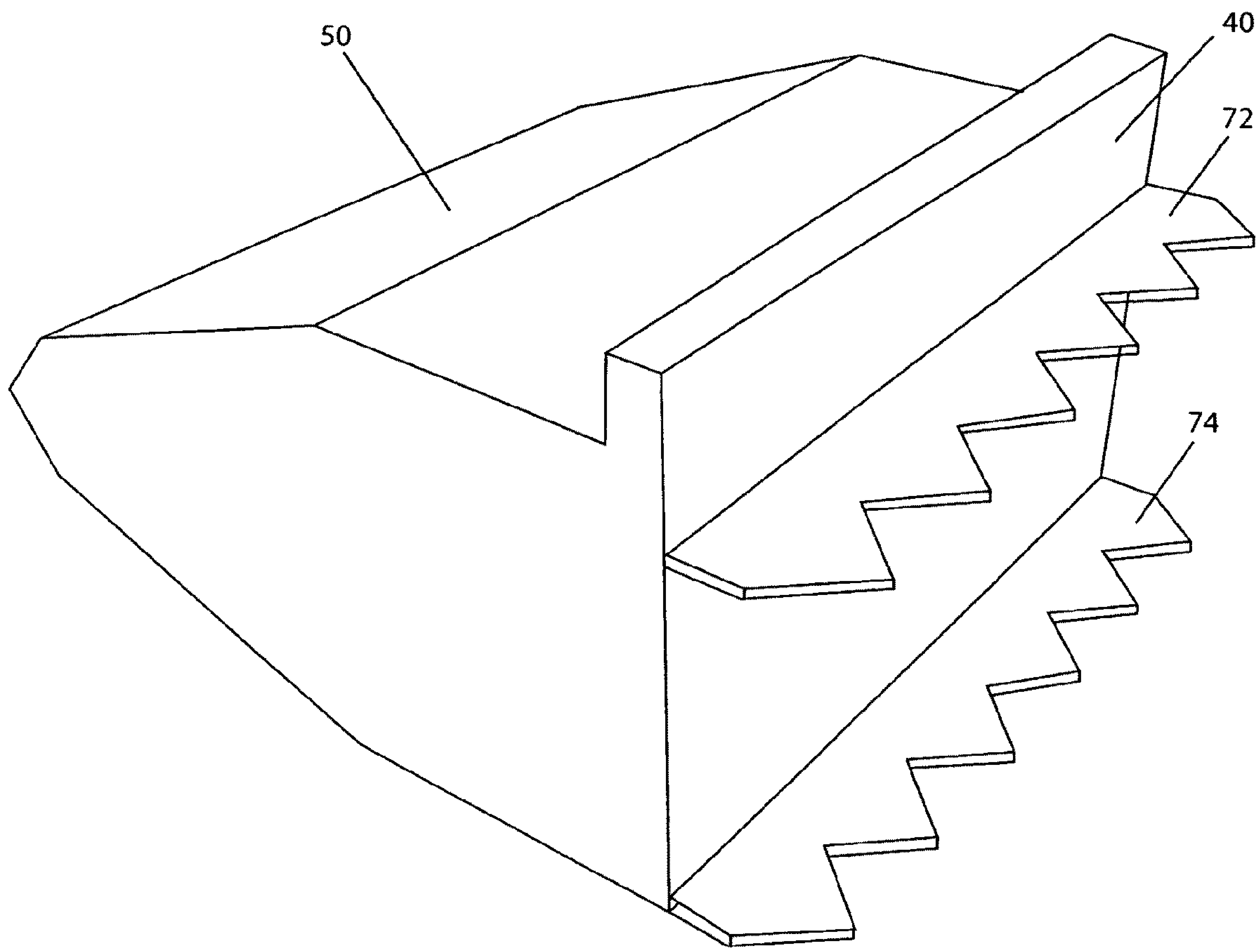


Fig. 3

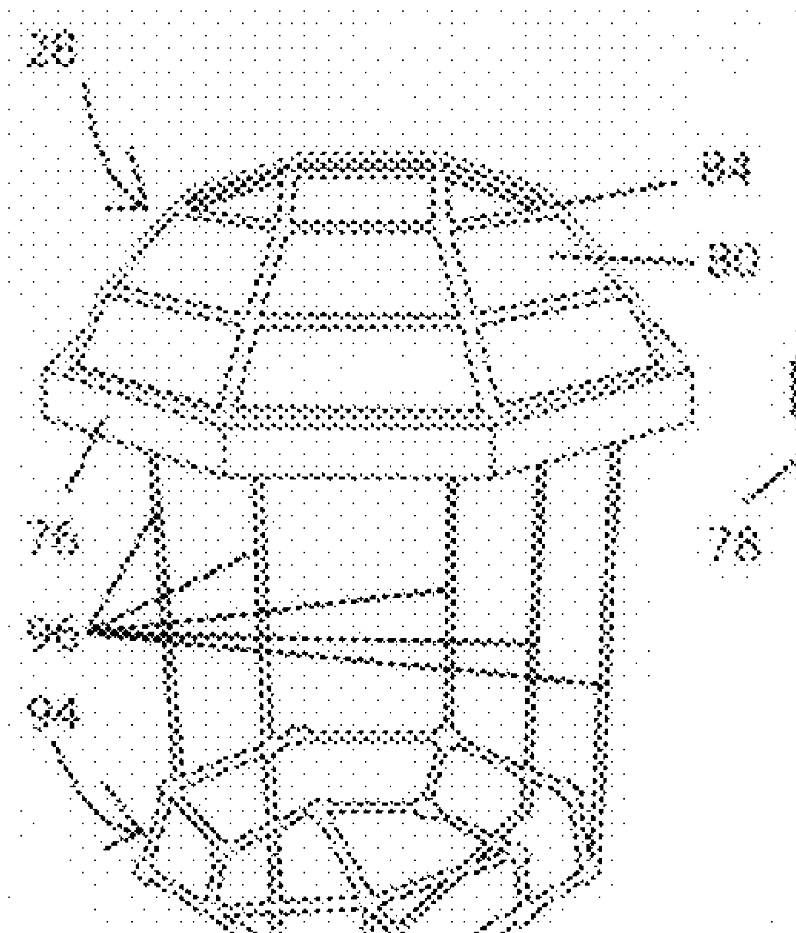


Fig. 4A

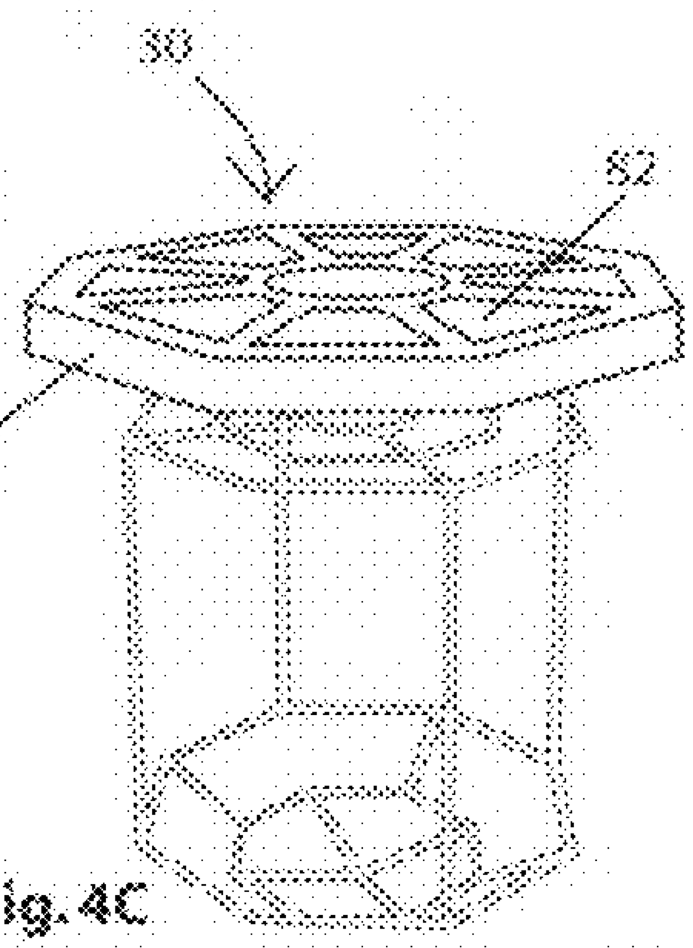


Fig. 4C

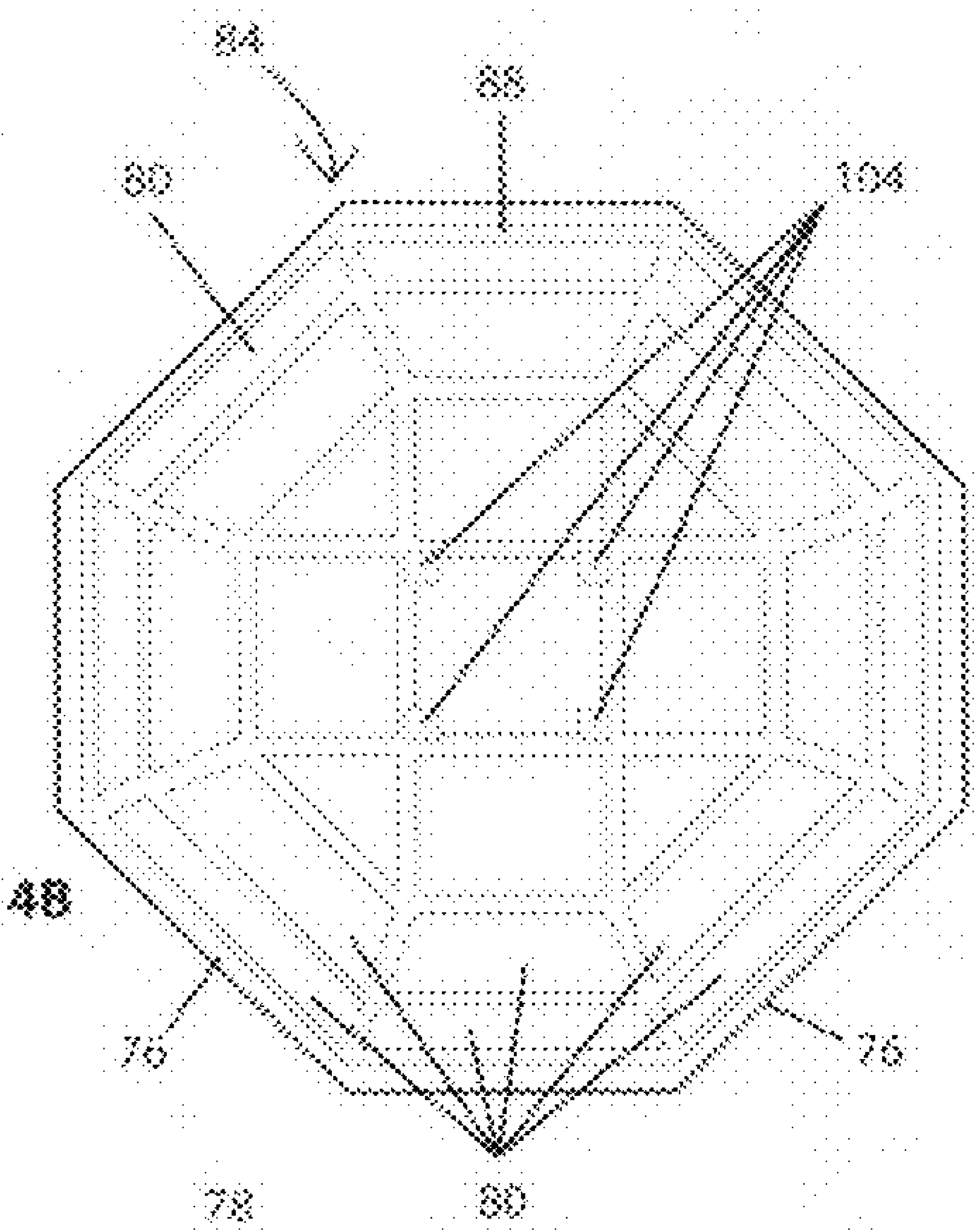


Fig. 4B

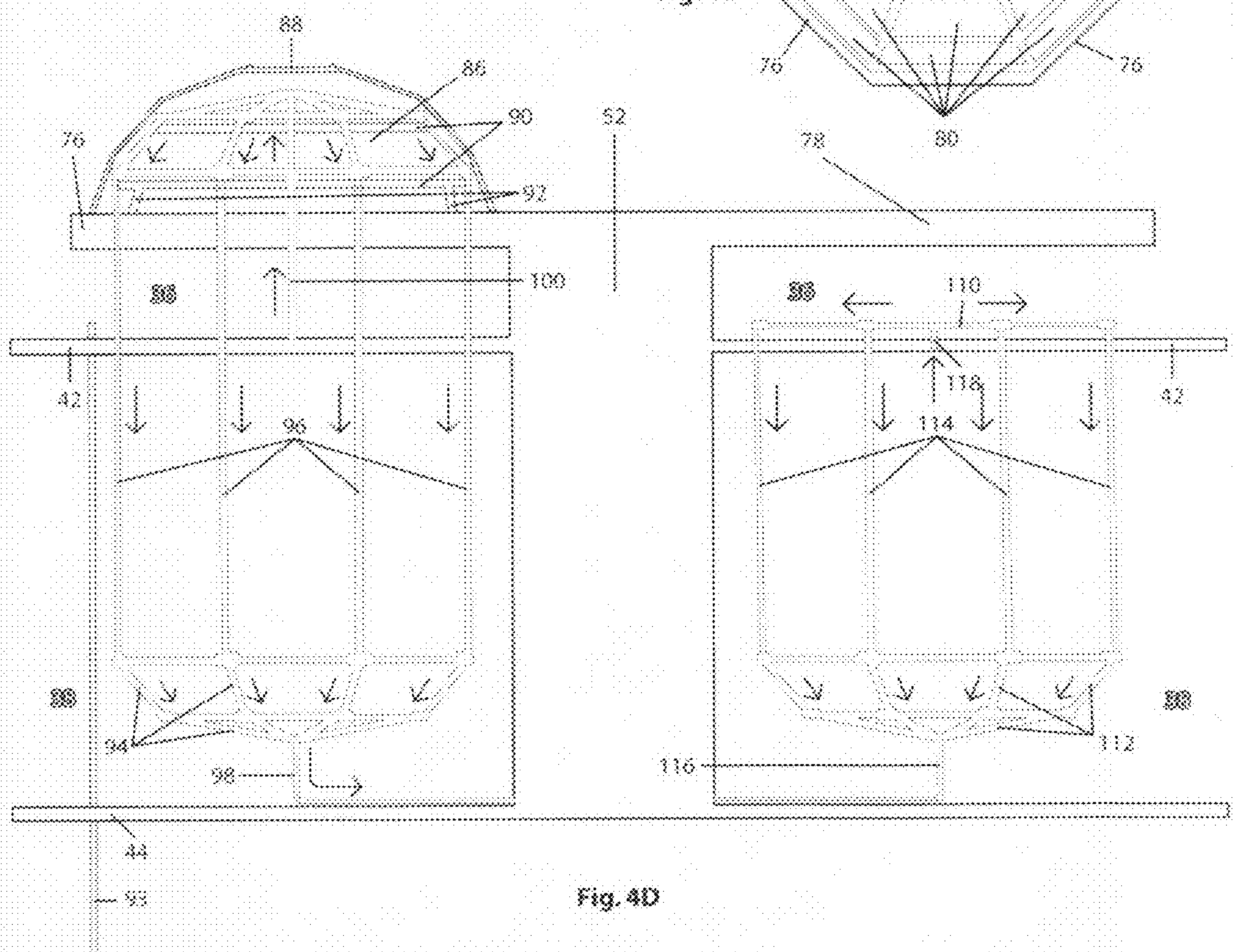


Fig. 4D

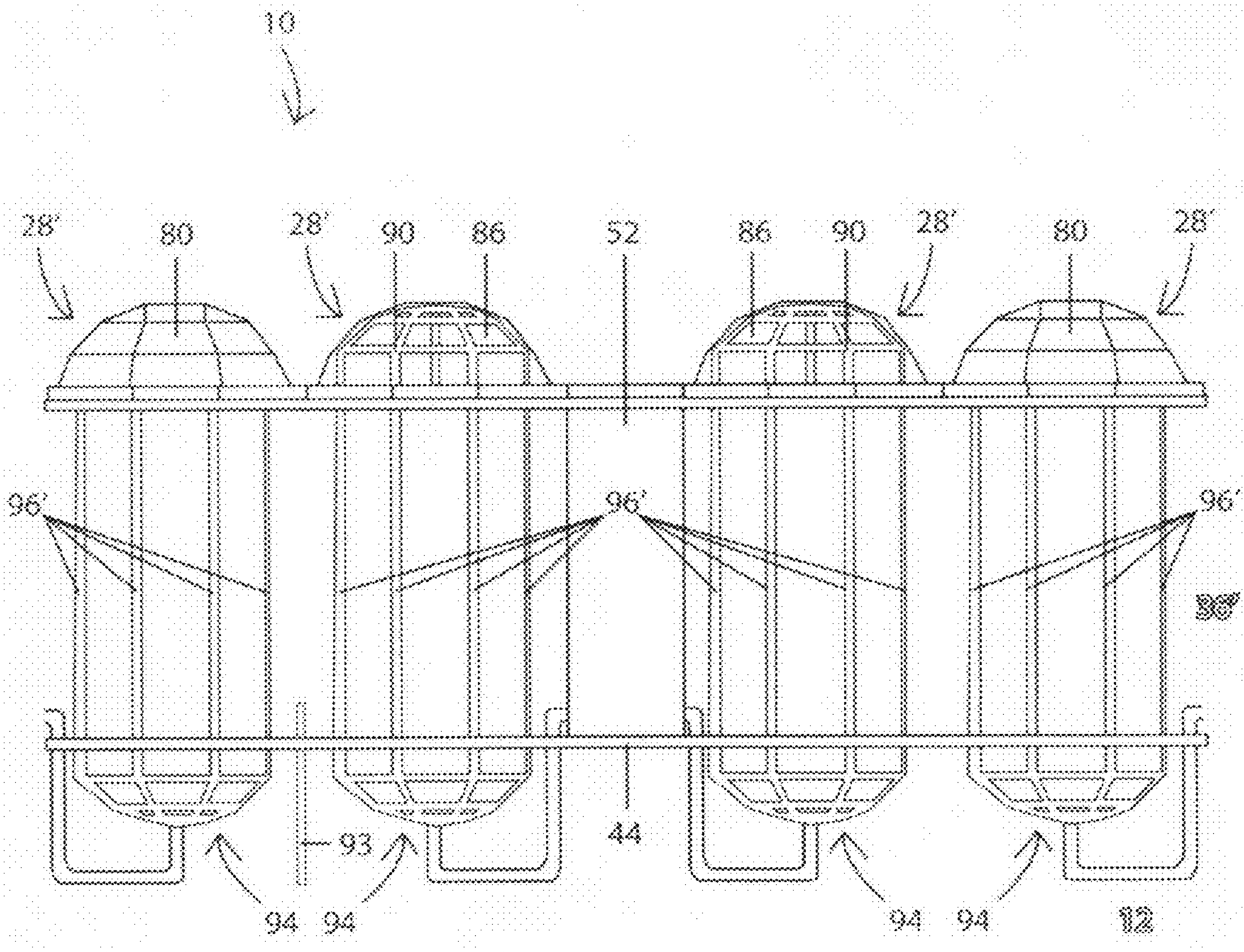


Fig. 5

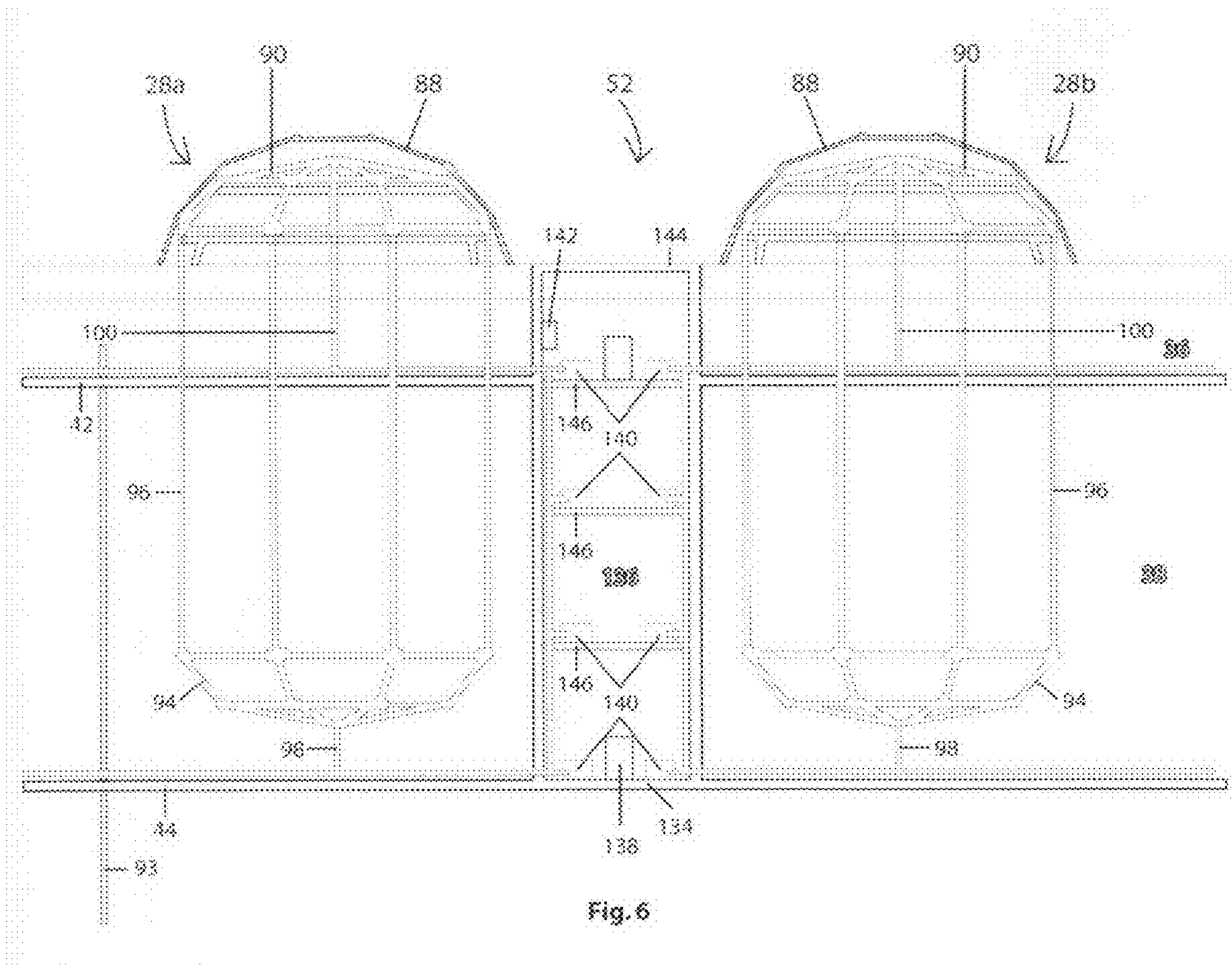

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Fig. 6

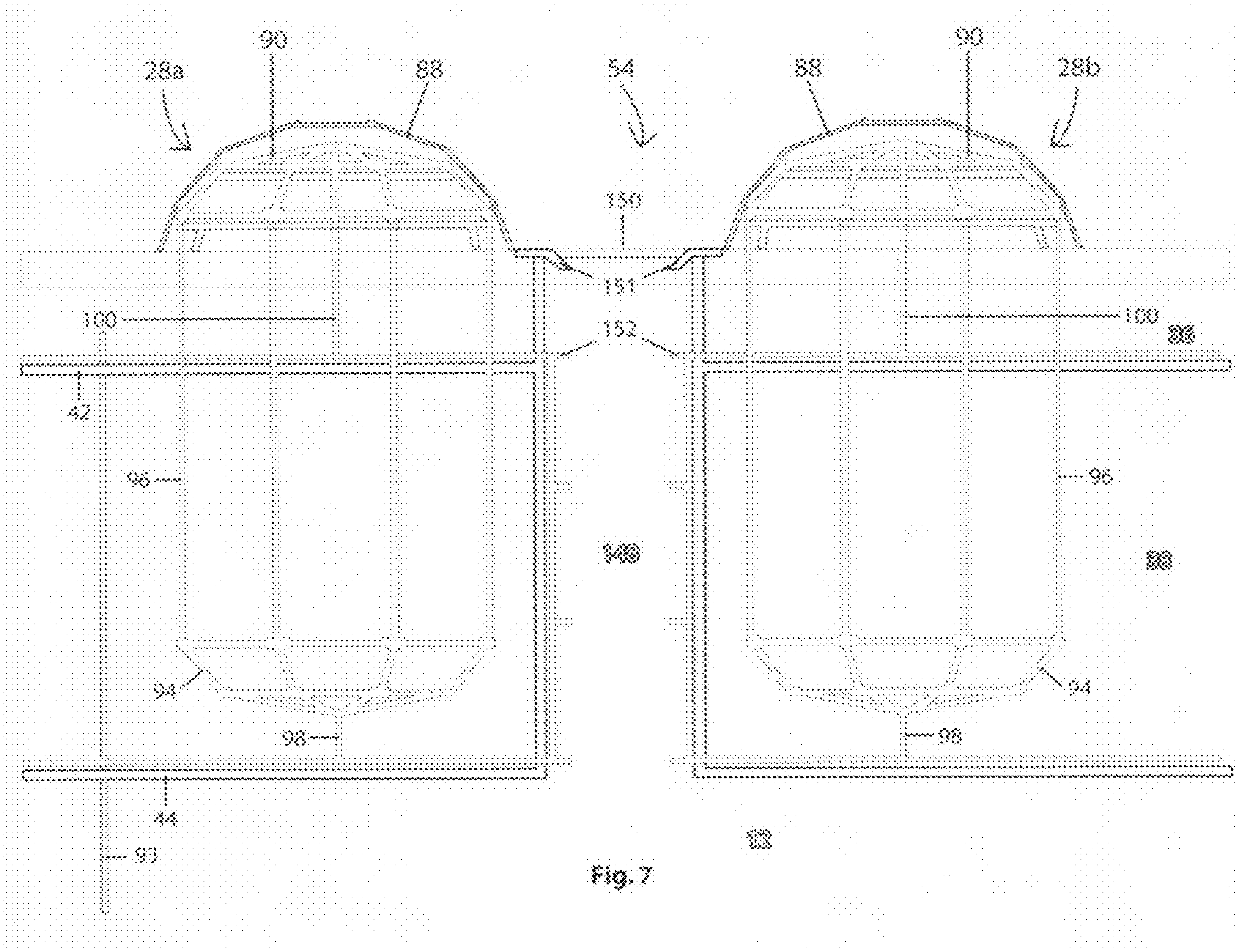

Fig. 7

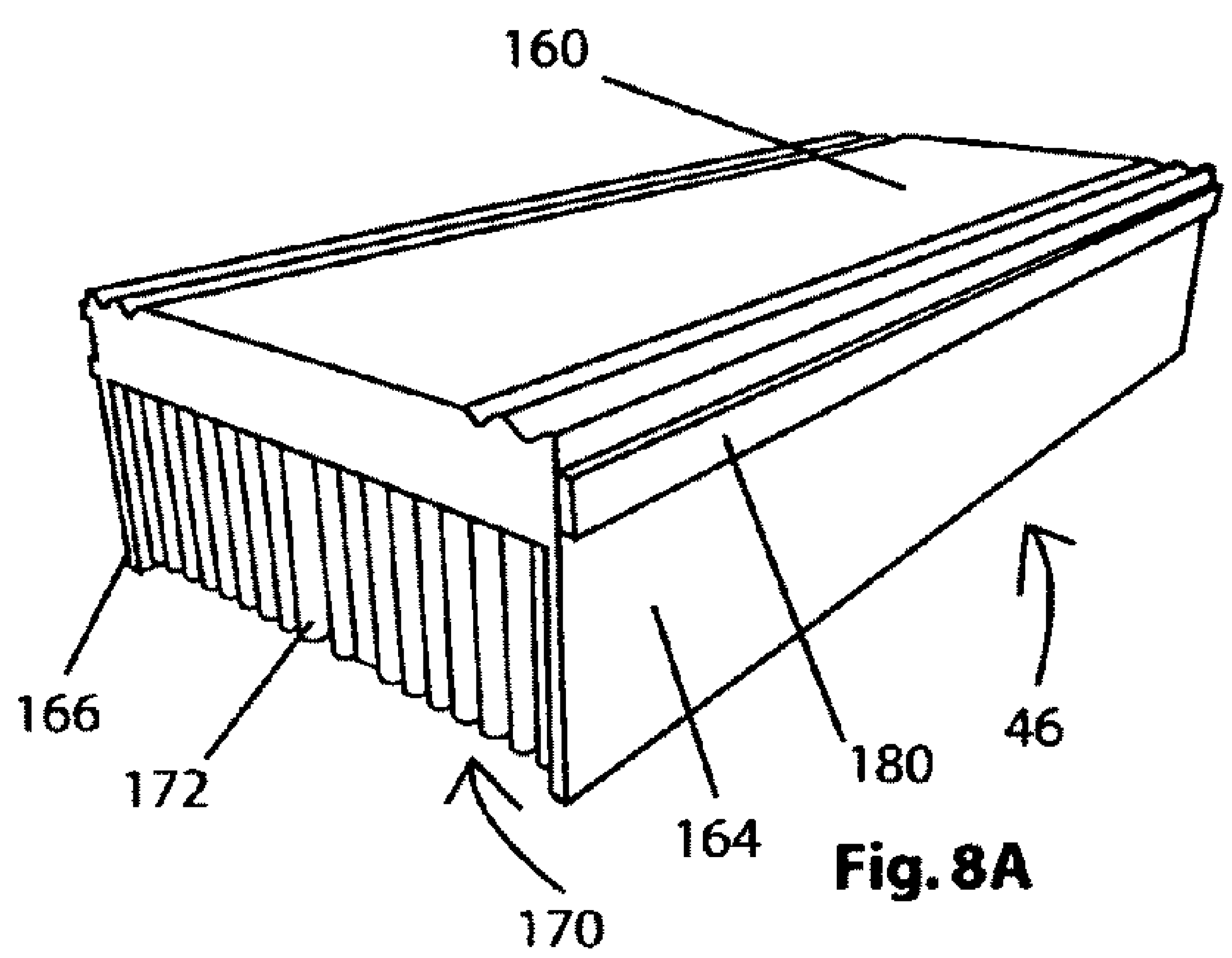

Fig. 8A

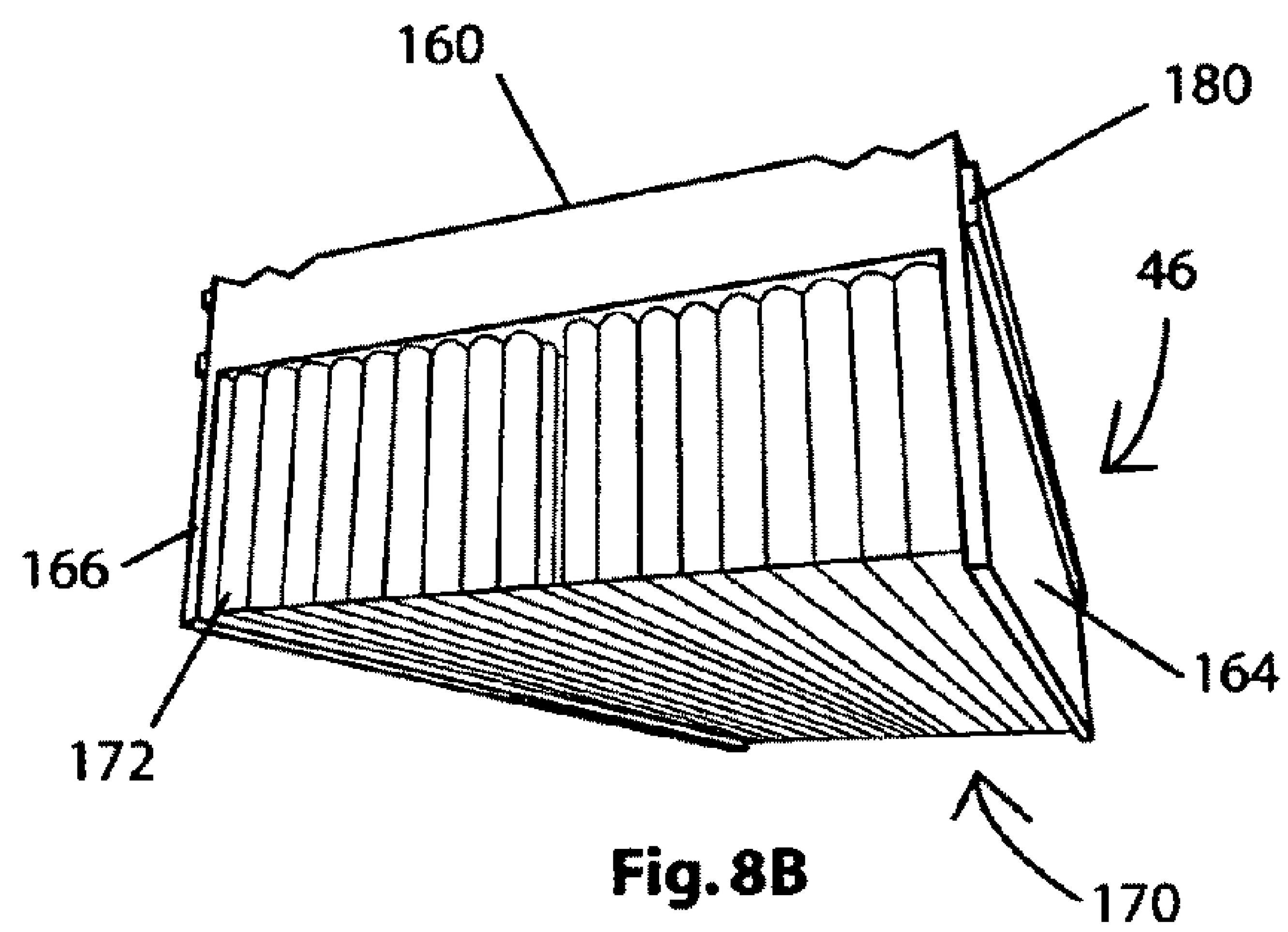

Fig. 8B

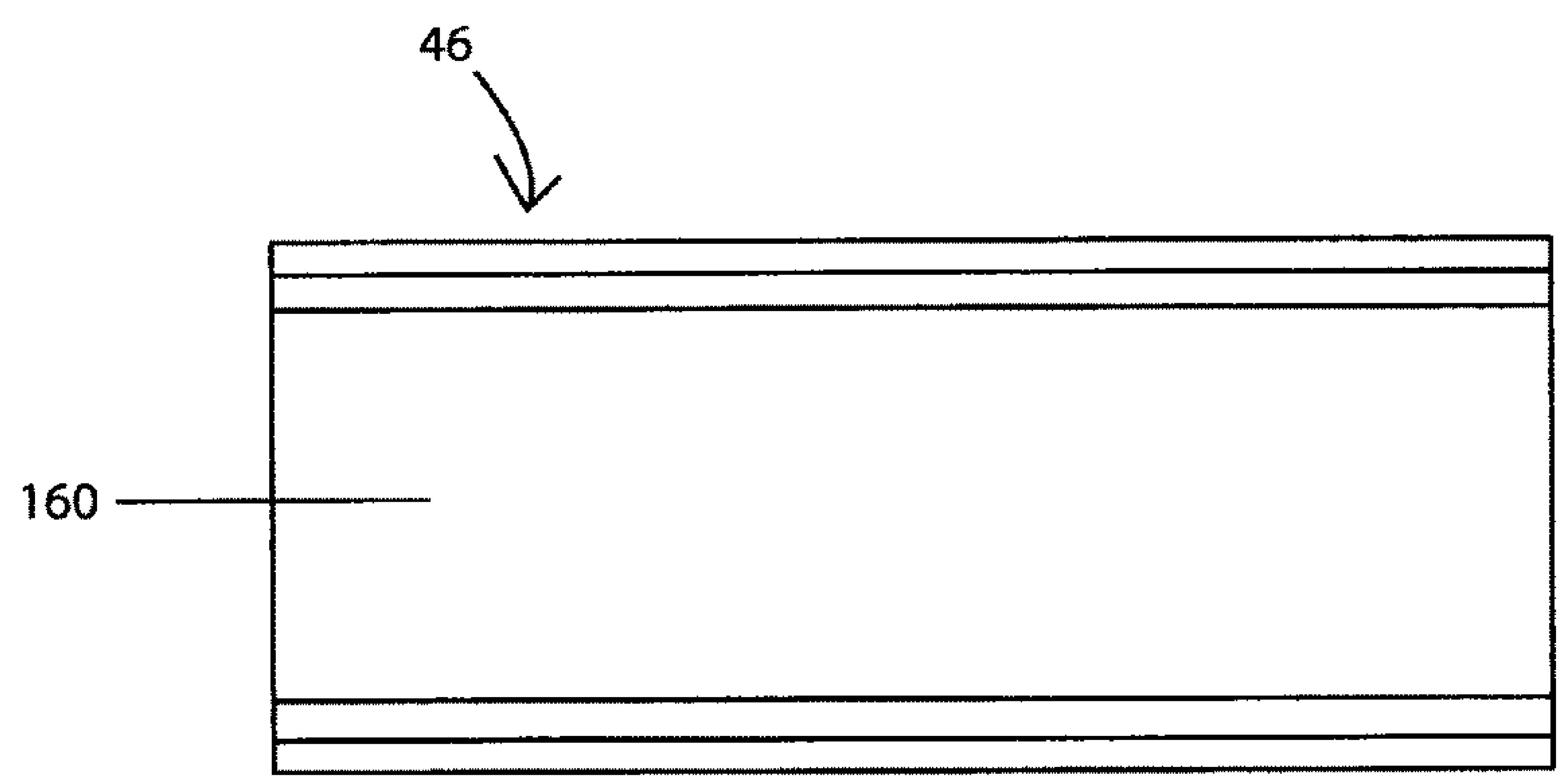

Fig. 8C

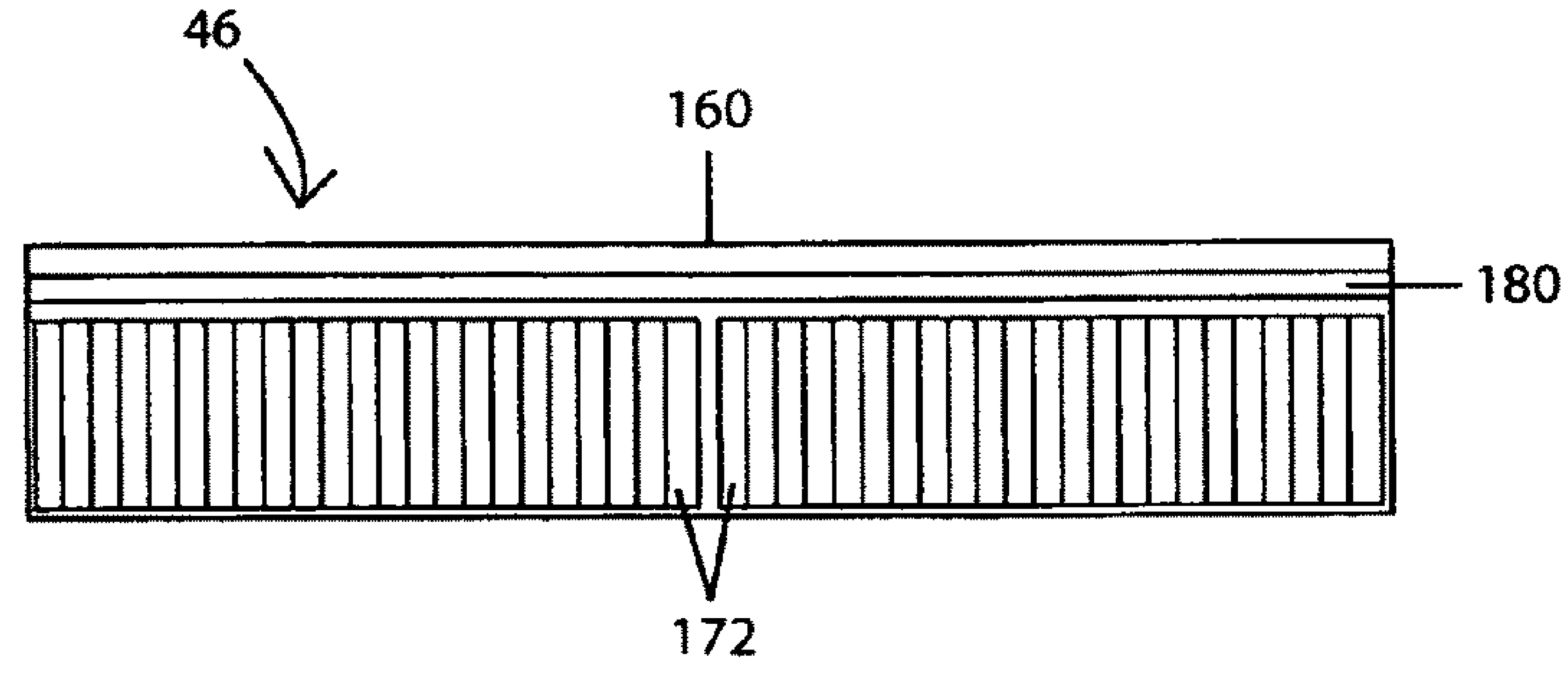

Fig. 8D

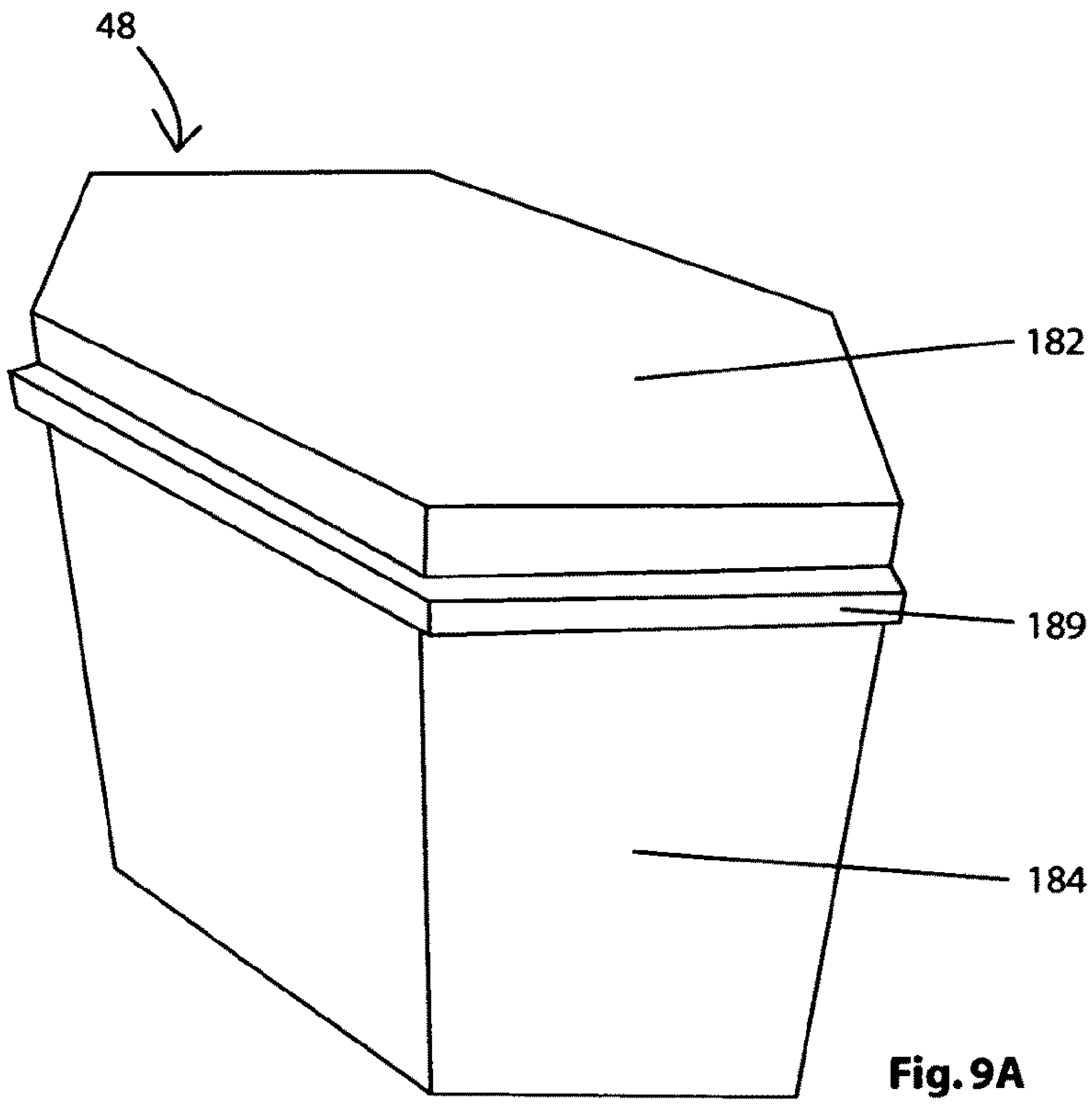

Fig. 9A

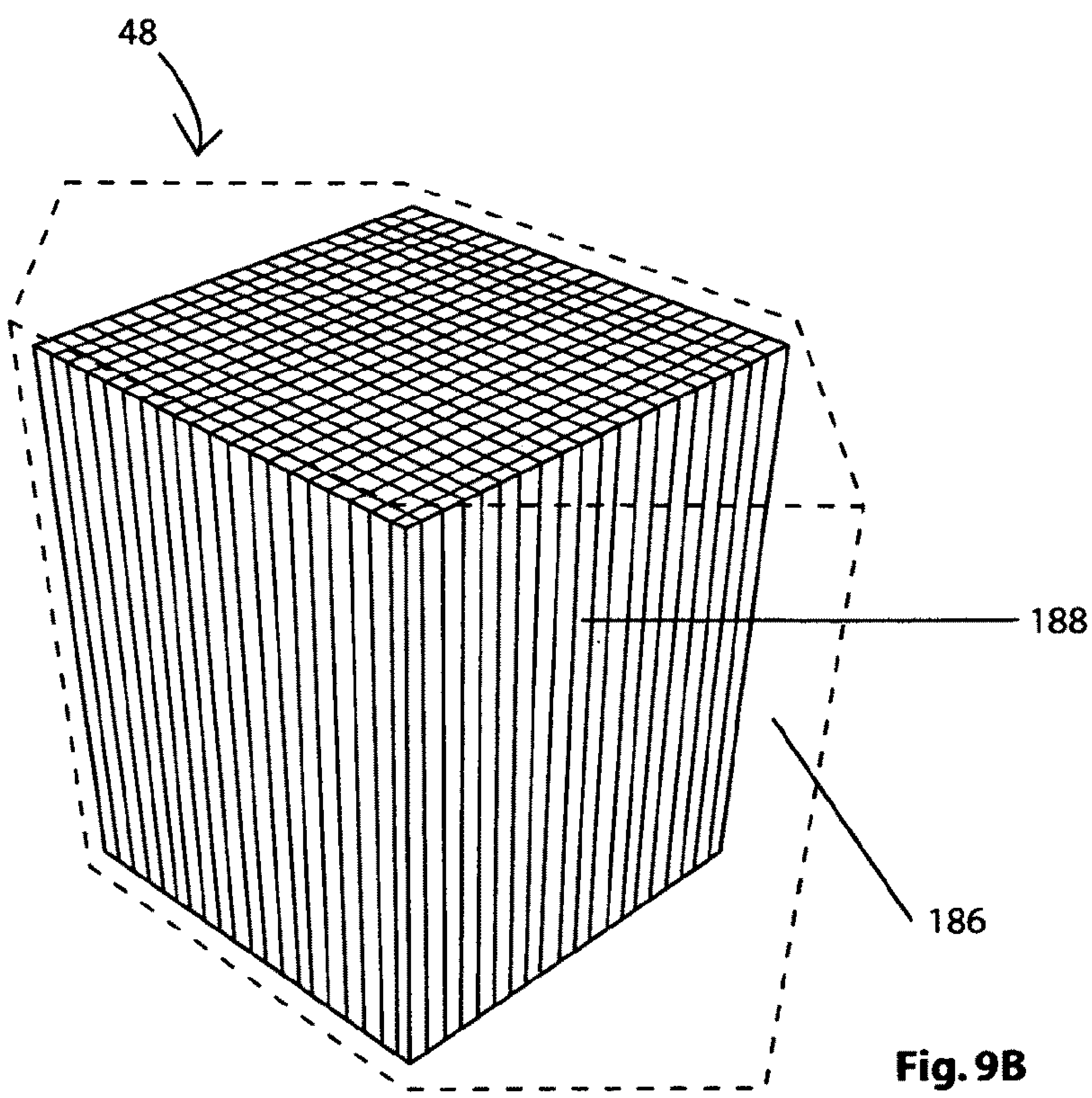

Fig. 9B

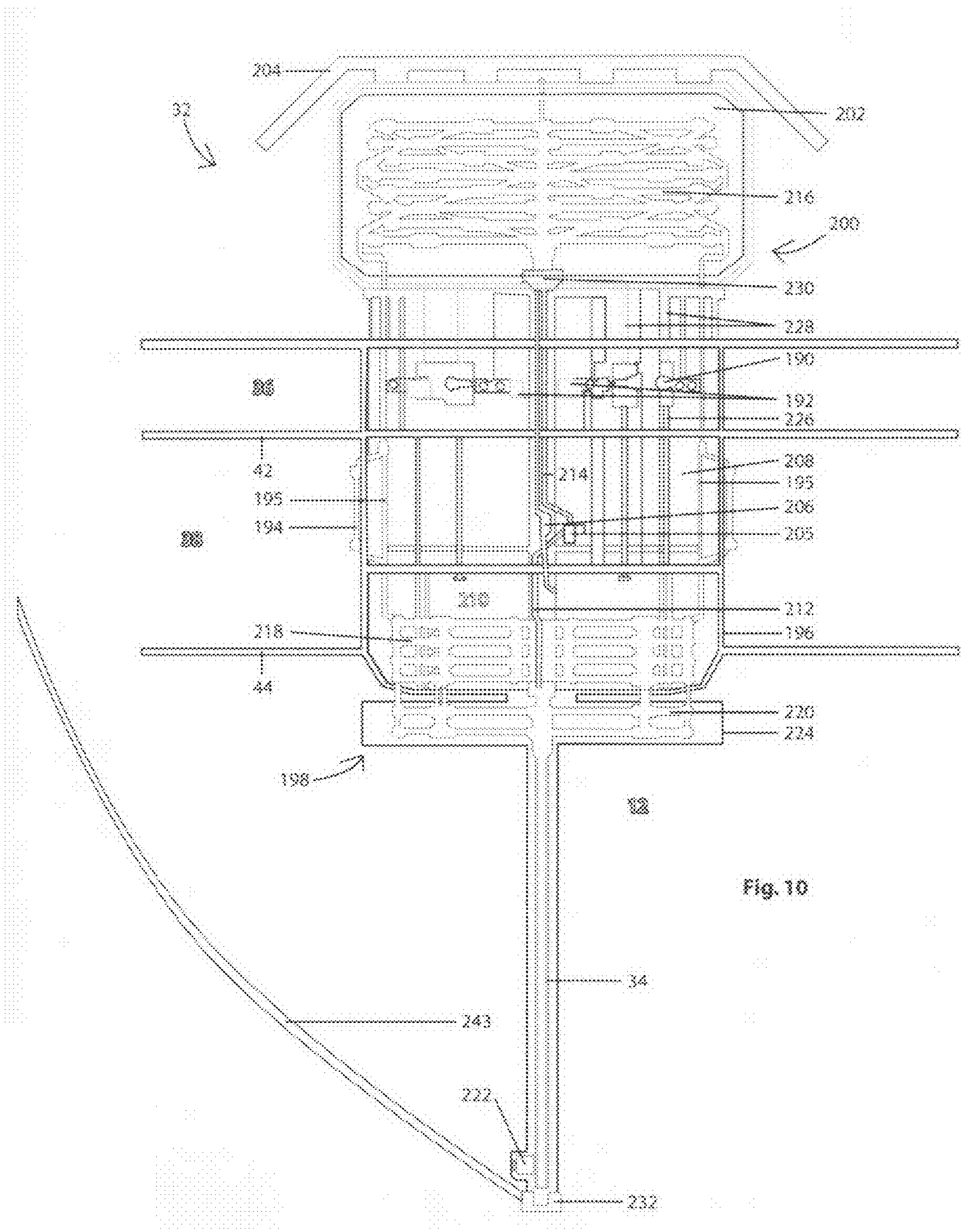
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Fig. 10

FLOATING SOLAR ENERGY CONVERSION AND STORAGE APPARATUS

RELATED APPLICATIONS

This application claims the filing date of U.S. Provisional Patent Application Ser. No. 60/977,986, filed Oct. 5, 2007.

BACKGROUND OF THE INVENTION

The present invention relates to a floating solar energy conversion and storage apparatus.

BACKGROUND OF THE INVENTION

Scientists recognized long ago the possibility of converting heat energy stored in oceans and other large bodies of water into a more useful form of energy such as electricity. The well-known Ocean Thermal Energy Conversion (OTEC) process utilizes the characteristic difference in temperature (20° C.) between solar-warmed surface water and deep cold water to power a closed-cycle or open-cycle heat engine. The closed-cycle approach utilizes a liquid refrigerant or working fluid (ammonia, for example) having a low boiling point. The warm surface water is pumped through an evaporator to boil the refrigerant and produce vapor for driving a low-pressure turbine-generator; and the cold deep water is pumped through a condenser to condense the spent vapor back into a liquid. In the open-cycle approach, the ocean water itself is the working fluid, and the process of boiling (by flash-evaporation typically) and condensing produces fresh (i.e., desalinated) water as a by-product. There are also hybrid systems that boil warm surface ocean water by flash-evaporation and direct the steam through an evaporator to vaporize a closed-cycle working fluid such as ammonia.

In practice, the above-described OTEC processes have met with only limited success because of the relatively small naturally occurring temperature difference between warm surface water and cold deep water. Accordingly, what is needed is an improved way of harnessing solar energy from a body of ocean or fresh water.

SUMMARY OF THE INVENTION

The present invention is directed to an improved energy conversion and storage apparatus that floats on a body of water and confines and stores a large quantity of solar-heated water for producing electricity with a closed-cycle heat engine. The apparatus includes an expansive horizontal structure parallel to the surface of the water for storing one or more horizontal layers of water, a distributed array of solar collectors for gathering solar energy and imparting it to the stored water, and one or more closed-cycle heat engines for producing electricity utilizing the temperature differential between the stored water and ambient water at a moderate depth such as 30 m. When configured for use in fresh water, the solar collectors can be configured to transfer collected solar energy to the stored water using a convective process; and when configured for use in salt water, some or all of the solar collectors can be configured to transfer collected solar energy to the stored water using a distillation process that produces desalinated water as a by-product.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is an overall isometric diagram of the apparatus of this invention as seen from above;

FIG. **1**B is a side view of the overall apparatus of FIG. **1**, including an energy conversion chamber, a heat storage chamber, convective and non-convective heat transfer structures, pump utility shafts, and drain shafts;

FIG. **2**A is a diagram of a preferred structure and fabrication method for horizontal barriers that bound the energy conversion and heat storage chambers of FIG. **1**;

FIG. **2**B depicts upper and lower horizontal barriers constructed as shown in FIG. **2**A;

FIG. **2**C is an isometric view of an irregular hexagonal section of the horizontal barrier of FIG. **2**A;

FIG. **2**D is a top view of the irregular hexagonal section of FIG. **2**C;

FIG. **2**E is a bottom view of the irregular hexagonal section of FIG. **2**C;

FIG. **3** depicts a seawall and wave energy absorber disposed at a periphery of the apparatus of FIGS. **1**A-**1**B;

FIG. **4**A depicts a convective solar collector according to this invention;

FIG. **4**B is a top view of the convective solar collector of FIG. **4**A;

FIG. **4**C depicts a non-convective solar collector according to a first embodiment of this invention;

FIG. **4**D is a side view depicting the convective and non-convective solar collectors of FIGS. **4**A and **4**C in the context of the apparatus of FIGS. **1**A-**1**B;

FIG. **5** is a diagram of a non-convective solar collector according to a second embodiment of this invention;

FIG. **6** is a side view of the pump utility shaft of FIG. **1**B;

FIG. **7** is a side view of the precipitate drain shaft of FIG. **1**B;

FIG. **8**A is an upper isometric diagram of a roadway according to this invention;

FIG. **8**B is a lower isometric diagram of the roadway of FIG. **8**A;

FIG. **8**C is a top view of the roadway of FIGS. **8**A-**8**B;

FIG. **8**D is cross-sectional view of the roadway of FIGS. **8**A-**8**B;

FIG. **9**A is an isometric diagram of a dock according to this invention;

FIG. **9**B is an isometric view of a ballast tube matrix inside the dock of FIG. **9**A; and

FIG. **10** is a diagram of the heat engine of FIG. **1**A.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. **1**A and **1**B, the reference numeral **10** generally designates a floating solar energy conversion apparatus according to this invention, configured for off-shore use in a body of seawater **12**. The apparatus **10** is anchored to the sea floor **14** by a distributed array of mooring cables **16**. For example, the apparatus **10** may be floating in 100 m of seawater, several thousand meters from shore **18**. The shore and near-shore facilities include a floating reservoir **20** for storing desalinated water, a pumping facility **22** for transferring desalinated water from reservoir **20** to a water distribution system, and an electricity transfer facility **23** for interfacing the apparatus **10** with a commercial electrical distribution system. Desalinated water produced by the apparatus **10** is transferred to reservoir **20** by a fresh water pipeline **24** extending downward to the seafloor **14**, and following the contour of seafloor **14** as shown. And electricity produced by apparatus **10** is transferred to the electricity transfer facility **23** by a set of electrical cables **26** bundled with the pipeline **24**. Optionally, an additional conduit may be provided for delivering concentrated mineral seawater to an on-shore processing facility.

In general, the apparatus **10** is a horizontally expansive water containment and heat storage system with a distributed array of heat transfer structures **28**, **30** for gathering solar energy and imparting it to the confined water, and one or more closed-cycle heat engines **32** for producing electricity utilizing the temperature differential between the confined water and ambient water drawn from a moderate depth through a set of downwardly extending ambient water heat exchanger conduits **34**. In the preferred embodiment, the apparatus **10** includes two horizontally expansive and overlapping chambers **36**, **38**. The uppermost chamber **36** confines a relatively small volume of seawater (with a depth of about 3 m, for example) on which solar energy impinging on the apparatus **10** is concentrated, and is also referred to herein as the Energy Conversion Chamber, or simply ECC. The lowermost chamber **38** contains a much larger volume of seawater (with a depth of 15 m, for example) for long-term heat storage, and is also referred to herein as the Heat Storage Chamber, or simply HSC. The energy conversion and heat storage chambers **36** and **38** are bounded laterally by a peripheral seawall **40**, and vertically by a pair of mutually-parallel horizontal barriers **42**, **44** fastened to seawall **40**. The barriers **42** and **44** form the upper and lower surfaces of Heat Storage Chamber **38**, and the uppermost barrier **42** also forms the bottom surface of Energy Conversion Chamber **36**. The heat transfer structures **28**, **30** and a network of roadways **46** float on the water stored in the Energy Conversion Chamber **36**, defining an atmospheric barrier for the apparatus **10**, as well as the upper boundary of Energy Conversion Chamber **36**. Floating docks **48** are secured to a shoreward-facing portion of the peripheral seawall **40**, and the remainder of seawall **40** is fitted with a sloped wave energy absorber **50** that protects the apparatus **10** from wave-related damage. Additionally, the seawall **40** may be designed to allow for drainage of seawater from very large waves that break over the seawall **40**. As illustrated in FIG. **1**A, the docks **48** support various structures **51** (storage building and living quarters, for example), and are configured to provide a sheltered docking area **53** for vessels.

As shown in FIG. **1**B, the apparatus **10** also includes a distributed array of pumping utility shafts **52** and precipitate drain shafts **54**. As described below in reference to FIG. **6**, the pumping utility shafts **52** house pumps for circulating closed-circuit heat exchange fluid (double distilled water, for example) though conduits within the heat transfer structures **28**, **30**. And as described below in reference to FIG. **7**, the precipitate drain shafts **54** serve as portals to the seawater beneath apparatus **10** for disposing of surface water from rain and wave action, and accessing submersible pumps used by the heat engines **32** and other ambient water heat exchangers.

As illustrated in FIGS. **2**A-**2**B, the horizontal barriers **42**, **44** preferably comprise a matrix of water-impermeable irregular hexagonal plates **56**, interlocked by peripheral double-tongue-in-groove features **58** to form an extensive water-impermeable seal. As seen more clearly in FIGS. **2**C-**2**E, each plate **56** comprises a core **60** of pressure-resistant insulation that blocks conduction of infrared energy, sandwiched between upper and lower layers **62**, **64** of water-impermeable material. In the illustrated embodiment, the core **60** and upper and lower layers **62**, **64** are fastened to each other mechanically by a distributed array of mechanical fasteners **66** and tension-bearing belts **68**. Additionally, each of the plates **56** may be fitted with a peripheral skirt **70** of water-impermeable material on three sides that overlaps adjacent plates **56** as shown for enhanced plate-to-plate sealing. At the periphery of the apparatus **10**, the plates **56** interface, again by double-tongue-in groove features, with inwardly extending ledges **72**, **74** formed on the inboard face of seawall **40**. As illustrated in FIG. **3**, the ledges **72**, **74** are notched to complement the peripheral outline of the hexagonal plate matrix to form a water-impermeable and gap-free peripheral coupling to the seawall **40**. FIG. **3** also illustrates a preferred configuration in which the seawall **40**, wave energy absorber **50**, and ledges **72**, **74** are formed as an integral unit of a given width, with like units secured side-by-side about the periphery of the apparatus **10**. The dock **48** on the shoreward side of apparatus **10** may be similarly constructed, if desired.

As indicated above in respect to FIG. **1**, the apparatus **10** includes a distributed array of heat transfer structures **28**, **30** floating on the water confined in the Energy Conversion Chamber **36** for admitting solar energy and imparting it to water confined in chambers **36** and **38**. In general, the heat transfer structures **28** transfer the collected solar energy to the confined water using a convection and distillation process, while the heat transfer structures **30** transfer the collected solar energy to the confined water using a non-convection or conduction process. Referring to FIGS. **4**A and **4**C, the heat transfer structures **28**, **30** each include a buoyant octagonal base **76**, **78** that supports a transparent barriers **80**, **82** through which solar radiation penetrates to warm the water in the Energy Conversion Chamber **36**. The bases **76**, **78** feature peripheral tongue-in-groove couplings so that multiple bases **76**, **78** may be arranged in a cluster and interlocked to form a water-tight seal between adjacent bases. Square-shaped or triangular-shaped gaps between bases **76**, **78** that are interconnected in this manner are filled with suitably shaped plates (not shown) having a construction similar to that of the horizontal barriers plates **56**, and sealed with the adjoining bases **76**, **78** and roadways **46**.

As illustrated in FIGS. **4**A, **4**B and **4**D, the transparent barrier **80** of each convective heat transfer structure **28** is formed in the shape of a dome **84** to define a vapor chamber **86** between the transparent barrier **80** and the surface of the water in Energy Conversion Chamber **36**. The transparent barrier **80**, which may comprise sealed sections of argon (or carbon-dioxide) filled double-paned glass, is supported by a hemispherical frame **88** of non-corrosive tubing extending upward from the octagonal base **76**. The argon-filled glass of transparent barrier **80** inhibits infrared heat loss; and in latitudes 40 or more degrees North or South of the equator, some of the heat transfer structures **28** may include a reflective coating on some of the transparent panels **80** to optimize solar energy input when the angle of solar incidence is low.

The hemispherical frame **88** of dome **84** also supports a upper hemispherical set of interconnected conduits defining an upper heat exchanger **90**, and associated troughs **92**, within the vapor chamber **86**, a lower hemispherical set of interconnected conduits defining an lower heat exchanger **94**, and a distributed array of vertical pipes **96** coupling the upper heat exchanger **90** to the lower heat exchanger **94**. Through-fittings are provided in the upper horizontal barrier **42** to accommodate the vertical pipes **96**. The upper heat exchanger **90** is disposed in the vapor chamber **86**, while the lower heat exchanger **94** is submerged in Heat Storage Chamber **38**. Essentially, solar energy collected through the transparent barrier **80** heats the water in Energy Conversion Chamber **36** so that the air in vapor chamber **86** has a high concentration of water vapor, and heat exchange fluid (double distilled water, for example) within the heat exchangers **90**, **94** and pipes **96** is circulated to transfer heat energy stored in the vapor to the water confined in the Heat Storage Chamber **38**. As described below in respect to FIG. **6**, a pump utility shaft **52** located in proximity to the heat transfer structure **28** houses pumps for circulating the heat exchange fluid through heat exchangers **90**, **94** and pipes **96**. A flexible return pipe **98** connected to the lower heat exchanger **94** is coupled to the inlet of a pump, and a flexible supply pipe **100** connects the outlet of the pump to the upper heat exchanger **90** so that the heat exchange fluid flows in a closed circuit as designated by the arrows in FIG. **4**D.

The distillation heat transfer process carried out in each convective heat transfer structure **28** works as follows. The heat exchange fluid circulating through the upper heat exchanger **90** in vapor chamber **86** chills the surface temperature of the conduits comprising heat exchanger **90** to a temperature below the dew point of the vapor-laden air in vapor chamber **86**. The latent heat of condensation is thereby transferred from the vapor to the heat transfer fluid in heat exchanger **90**. At the same time, the condensate coalesces and drips off the heat exchanger conduits into the underlying troughs **92**, which channel the condensate and direct it to a system reservoir (not shown). As the heat exchange fluid passes downward through the vertical pipes **96** and into the lower heat exchanger **94**, it releases the absorbed heat of condensation to the water confined in Heat Storage Chamber **38**. The temperature of the heat exchange fluid is thereby lowered below the dew point of the air in vapor chamber **86** so that vapor continuously condenses on the upper heat exchanger **90** in vapor chamber **86**. The condensate removed via troughs **92** is replaced with fresh seawater via an ambient water delivery pipe **93**, which enters the apparatus **10** via suitable through-fittings in the upper and lower horizontal barriers **42** and **44**. And since the condensation process gradually increases the salinity of the water confined in Energy Conversion Chamber **36**, the water in chamber **36** can be periodically purged and replaced with fresh seawater from the ambient water delivery pipe **93**.

The dome **84** of each convective heat transfer structure **30** is additionally equipped with an exhaust fan (not shown) and one-way inlet valve (not shown). The exhaust fan is periodically activated to exchange the air in vapor chamber **86** with fresh atmospheric air to release non-condensing gasses and thereby maximize condensation and the associated heat transfer. Also, the dome **84** is equipped with one or more atmospheric vents **104** that open when the barometric pressure is below the vapor pressure in the vapor chamber **86**, as can occur under certain atmospheric conditions.

As illustrated in FIGS. **4**C and **4**D, the transparent barrier **82** of each non-convective heat transfer structure **30** is planar and horizontal. Similar to the convective heat transfer structures **28**, each non-convective heat transfer structure **30** includes a heat exchange fluid circulated through a set of interconnected conduits defining an upper heat exchanger **110**, a lower hemispherical set of interconnected conduits defining a lower heat exchanger **112**, and a distributed array of vertical pipes **114** coupling the upper heat exchanger **110** to the lower heat exchanger **112**. The flexible return pipe **116** couples the lower heat exchanger **114** to the inlet of a pump, and the flexible supply pipe **118** connects the outlet of the pump to the upper heat exchanger **110** so that the heat exchange fluid flows in a closed circuit as designated by the arrows in FIG. **4**D. However, the non-convective heat transfer structures **30** have no vapor chamber; the heat exchanger **110** is submerged in the Energy Conversion Chamber **36**, and the lower heat exchanger is submerged in the Heat Storage Chamber **38**. The heat exchange fluid passing through the upper heat exchanger **110** absorbs heat from the solar-heated water of the Energy Conversion Chamber **36**, and then releases the heat to the water stored in the Heat Storage Chamber **38** when it passes through the lower heat exchanger **112**. Since the upper heat exchanger **110** is submerged in nearly 3 m of water, the heat exchange fluid remains under substantial pressure. As a result, the heat exchange fluid remains in a liquid state, and transfers heat to the Heat Storage Chamber **398** at a significantly higher temperature than the convective heat transfer process carried out in the heat transfer structures **28**.

FIG. **5** illustrates an alternate embodiment of the apparatus **10** and convective heat transfer structures **28'** that is particularly useful in locations of high solar incidence and relatively warm ambient water, where large amounts of distilled (desalinated) water are desired. In this case, the Energy Conversion Chamber **36** and Heat Storage Chamber **38** are combined into a single chamber **36'** that both converts and stores solar energy, and the lower heat exchanger **94** is disposed in the ambient seawater **12**. Through-fittings are provided in the horizontal barrier **44** to accommodate passage of the vertical conduits **96**. Condensation is enhanced because the heat transfer fluid in the upper heat exchanger **90** is colder due to the chilling effect of the ambient seawater **12** on the heat transfer fluid passing through the lower heat exchanger **94**.

FIG. **6** depicts a pumping utility shaft **52** disposed between a pair of heat transfer structures **28***a* and **28***b*, though it will be understood that each pumping utility shaft **52** is equipped with enough pumps to service several heat transfer structures. The side wall **132** and floor **134** seal the utility shaft **52** from Energy Conversion Chamber **36** and Heat Storage Chamber **38** and the ambient seawater **12** to provide a dry chamber **136** at atmospheric pressure for housing various motor-driven pumps **138**, **140** and one or more air compressors **142**. Sealed through fittings provide leak-proof wall openings for accommodating the return and supply pipes **98**, **100**, compressed air pipe (not shown), and electrical conduits (also not shown). A removable cover **144** at the top of the chamber **136** provides maintenance access, and a bilge pump **138** located under a grating (not shown) on the floor **134** purges the chamber **136** of any seawater or precipitate that enters through the removable cover **144**. The pumps **140** are disposed on peripheral shelves **146** at different levels of the chamber **136**, and serve to circulate heat exchange fluid through the heat exchangers of heat transfer structures **28**, **30**. The heat exchange fluid is delivered to the pumps **140** at the lowest level via the return pipes **98** and then supplied to the corresponding supply pipes **100**. The air compressor(s) **142** provide compressed air to the roadways **46** and docks **48** as explained below for maintaining a consistent elevation of the atmospheric barrier.

FIG. **7** depicts a precipitate drain shaft **54** disposed between a pair of heat transfer structures **28***a* and **28***b*. The sidewall **146** seals the precipitate drain shaft **54** from Energy Conversion Chamber **36** and Heat Storage Chamber **38**, but the bottom of precipitate drain shaft **54** is open to the ambient seawater **12** as shown. A removable grating **150** covers the top of the drain shaft **54** to drain runoff water and to permit access for maintenance. As mentioned above, the precipitate drain shaft **54** is used to dispose of precipitation and other unwanted water, and also to provide a portal for accessing and servicing submersible pumps used by ambient water heat exchangers. Precipitation and other water at the surface of apparatus **10** enters the precipitation drain shaft **54** via grating **150** and drain pipes **151** located near the top of the shaft **54**. And water from nearby bilge pumps **138** enters shaft **54** via evacuation pipes **152**. In the illustrated embodiment, the evacuation pipes **152** pass through the sidewall **146** just above the upper horizontal barrier **42**. The level of seawater within the precipitation drain shaft **54** is the same as the level of the ambient seawater **12** in which the apparatus **10** floats, and the buoyancy of the apparatus **10** is such that the level of seawater in shaft **54** is a foot or so below the level of precipitation drain pipes **151**.

FIGS. **8**A-**8**D depict a section of roadway **46**. Each roadway section includes a road surface **160**, and a pair of sidewalls **164**, **166** defining a flotation chamber **170** below road surface **160**. A matrix of vertically oriented hollow ballast tubes **172** are arranged within the flotation chamber **170**, such that the upper end of each ballast tube **172** is adapted to receive compressed air from an air conduit (not shown) for controlling the buoyancy of the roadway **46**, and the lower end of each ballast tube **172** opens into the water confined by Energy Conversion Chamber **36**. The upper ends of the ballast tubes **172** are interconnected by a series of air couplings (not shown) to equalize the air pressure in all of the ballast tubes **172**. This, along with a similar mechanism in docks **48**, is the principle mechanism for maintaining a consistent elevation of the entire atmospheric barrier. Other conduits such as electrical conduits and distilled water pipes (not shown) may be routed along the roadway **46**. When the roadway **46** is disposed adjacent a heat transfer structure **28**, **30**, a shoulder **180** formed on the sidewall **164** overlaps and seals against the bases **76**, **78** of the adjacent heat transfer structures **28**, **30**.

As shown in FIGS. **9**A and **9**B, dock **48** is formed of interlocking irregular hexagonal sections, each comprising an upper working surface **182** and depending sidewalls **184** defining an open-ended flotation chamber **186** within which are arranged a matrix of vertically oriented hollow ballast tubes **188**. As with the ballast tubes **172** of roadway sections **46**, compressed air is coupled to the upper ends of ballast tubes **188** to control the water level in ballast tubes **188**, and hence, the buoyancy of the docks **48**. When the dock section **48** is disposed adjacent a heat transfer structure **28**, **30**, shoulder **189** formed on the adjacent sidewalls **184** overlap and seal against the bases **76**, **78** of the heat transfer structures **28**, **30**.

FIG. **10** depicts one of the closed-cycle heat engines **32** that produce electricity utilizing the temperature differential between the confined water in Heat Storage Chamber **38** and ambient seawater **12** drawn from a moderate depth (100 m, for example) through the ambient water heat exchanger conduit **34**. Two thermally coupled closed-loop fluid circuits are used to produce vapor for driving one or more low-pressure turbines **190**, which in turn drive one or more generators **192** for producing electricity. A portion of the electricity produced by generators **192** is used within apparatus **10** to power the various motor-driven pumps, air compressors, and other equipment, while the remainder is delivered to on-shore electricity transmission station **23** via the power cables **26** bundled with seabed pipeline **24**.

In general, heat exchange (HX) fluid such as double-distilled water is circulated through the first fluid circuit, and a low boiling point working fluid such as ammonia is circulated through the second fluid circuit. Heat is added to the HX fluid by passing all or a portion of it through heat transfer pipes **194** disposed in the Heat Storage Chamber **38**, and the heated HX fluid is directed to an evaporator **196** where the heat stored in the HX fluid is used to boil the working fluid to produce vapor for driving the turbines **190**. The HX fluid is then chilled by circulating it through an ambient seawater heat exchanger **198**, and directed to a condenser **200** where the working fluid vapor used to drive turbines **190** condenses back into a liquid state, transferring its heat to the HX fluid. The liquid working fluid is returned via a high pressure pump to the evaporator **196** to be re-boiled, and additional heat it added to the HX fluid by passing all or a portion of it through heat transfer pipes **194** in Heat Storage Chamber **38**, completing the cycle.

Referring more specifically to FIG. **10**, the components of heat engine **32** are vertically arranged as shown. The condenser **200** is disposed in an insulated condenser chamber **202** above the horizontal barriers **42**, **44**, and covered by solar shield **204**. The turbines **190**, generators **192**, and pumps **205**, **206** for the HX and working fluid are disposed in a open shaft **208** below the condenser **200**. The evaporator **196** is disposed in a sealed evaporator chamber **210** below the open shaft **208**, and the ambient seawater heat exchanger **198** is disposed in the ambient seawater **12** below the horizontal barrier **44**.

The HX fluid is continuously circulated by the motor-driven HX pump **205**. Beginning at the ambient seawater heat exchanger **198**, chilled HX fluid is drawn upward through conduit **212** and pumped through conduit **214** to a network of heat transfer pipes **216** in the insulated condenser chamber **202**. The HX fluid is warmed due to condensation of working fluid surrounding the pipes **216**, and the warmed HX fluid is further heated when it passes through the heat transfer pipes **194** in Heat Storage Chamber **38** enroute to a network of heat transfer pipes **218** in the sealed evaporator chamber **210**. The portion of the HX fluid that passes through the heat transfer pipes **194** is controlled via the bypass pipes **195** and a set of valves in chamber **218** to regulate the temperature of the HX fluid supplied to the heat transfer pipes **218** of evaporator **196**. After circulating through the heat transfer pipes **216**, the HX fluid is directed to a network of heat transfer pipes **220** in the ambient seawater heat exchanger **198**. An ambient seawater pump **222** disposed near the bottom of the ambient water heat exchanger conduit **34** pumps cold seawater into a shroud **224** surrounding the heat transfer pipes **220** to chill the HX fluid, whereupon the HX fluid is pumped back to the condenser chamber **202** to complete the cycle. The cold seawater directed to the shroud **224** is exhausted to ambient seawater **12** through exhaust openings (not shown) in shroud **224**.

The working fluid is circulated by expansion and by the high pressure pump **206**. When the working fluid surrounding the heat transfer pipes **218** in sealed evaporator chamber **210** boils, the expanded working fluid (i.e., vapor) is expelled upward to turbines **190** through insulated pipes **226**. Working fluid vapor exhausted from the turbines **190** is directed to the insulated condenser chamber **202** via ducts **228**. When the working fluid vapor surrounding the heat transfer pipes **216** in condenser chamber **202** condenses, it collects in a reservoir **230** at the bottom of chamber **202**, and is periodically pumped back into the sealed evaporator chamber **210** by the high pressure working fluid pump **206**.

As shown in FIG. **10**, the flexible ambient water heat exchanger conduit **34** terminates in a marine life barrier and anti-fouling device **232**, and a tether **243** such as a cable is connected to the barrier **232** for drawing the pump-end of flexible conduit **34** to the surface of the apparatus for pump maintenance. In particular, the other end of tether **243** is routed up into one of the precipitate drain shafts **54** so that the pump maintenance can be conveniently performed at that location.

In summary, the floating solar energy conversion and storage apparatus **10** of the present invention overcomes many of the drawbacks and limitations of the known OTEC systems. While described with respect to the illustrated embodiments, it is recognized that numerous modifications and variations in addition to those mentioned herein will occur to those skilled in the art. For example, geometric shapes, materials and fluids other than those shown and described herein may be used, and so on. Accordingly, it is intended that the invention not be limited to the disclosed embodiment, but that it have the full scope permitted by the language of the following claims.

The invention claimed is:

1. A floating solar energy conversion and storage apparatus, comprising:

a horizontally expansive heat storage chamber floating in a body of ambient water and confining a volume of solar heated water;

a heat engine including an evaporator for vaporizing a working fluid therein, generating means for utilizing vaporized working fluid to produce electricity, and a condenser downstream of the generating means for condensing the vaporized working fluid therein and returning it to the evaporator;

a first circulating loop of heat exchange fluid that is heated by the confined volume of solar heated water in the heat storage chamber and directed to the evaporator to vaporize the working fluid therein, and that is chilled by said ambient water and directed to the condenser to condense the working fluid therein; and

an array of heat transfer structures for producing distilled water, each such heat transfer structure including a transparent dome for collecting solar energy and defining a vapor chamber above the water confined in said heat storage chamber, a first heat exchanger suspended in said vapor chamber, and a chilled heat exchange fluid flowing through said first heat exchanger so that water vapor in said vapor chamber condenses on said first heat exchanger to produce said distilled water.

2. The floating solar energy conversion and storage apparatus of claim 1, where said heat transfer structure further comprises:

a second heat exchanger connected in series with said first heat exchanger, and a pump for producing a circulating flow of heat exchange fluid through a closed circuit including said first and second heat exchangers, said second heat exchanger being disposed in said ambient water so that heat exchange fluid passing through said second heat exchanger is chilled by said ambient water before being circulated through said first heat exchanger.

3. A floating solar energy conversion and storage apparatus, comprising:

a horizontally expansive heat storage chamber floating in a body of ambient water and confining a volume of solar heated water;

a heat engine including an evaporator for vaporizing a working fluid therein, generating means for utilizing vaporized working fluid to produce electricity, and a condenser downstream of the generating means for condensing the vaporized working fluid therein and returning it to the evaporator;

a first circulating loop of heat exchange fluid that is heated by the confined volume of solar heated water in the heat storage chamber and directed to the evaporator to vaporize the working fluid therein, and that is chilled by said ambient water and directed to the condenser to condense the working fluid therein;

a horizontally expansive energy conversion chamber disposed above said heat storage chamber, and confining a volume of water that is directly heated by solar energy; and

a distributed array of heat transfer structures for transferring heat from said energy conversion chamber to said heat storage chamber.

4. The floating solar energy conversion and storage apparatus of claim 3, further comprising:

a transparent barrier floating on the water confined in said energy conversion chamber, and through which the water confined in said energy conversion chamber is directly heated by said solar energy.

5. The floating solar energy conversion and storage apparatus of claim 3, where one or more of said heat transfer structures comprises:

a domed transparent barrier through which the water confined in said energy conversion chamber is directly heated by said solar energy, said transparent barrier defining a domed vapor chamber above the water confined in said energy conversion chamber;

a first heat exchanger disposed in said vapor chamber;

a second heat exchanger submerged in said heat storage chamber; and

a pump for producing a circulating flow of heat exchange fluid through a closed circuit including said first and second heat exchangers so that heat energy added to said heat exchange fluid due to condensation of water vapor on said first heat exchanger is transferred to the water confined in said heat storage chamber when said heat exchange fluid flows through said second heat exchanger.

6. The floating solar energy conversion and storage apparatus of claim 4, further comprising:

collection means suspended in said vapor chamber for collecting liquid condensate produced by the condensation of said water vapor on said first heat exchanger; and

storage means for storing condensate collected by said collection means.

7. The floating solar energy conversion and storage apparatus of claim 4, where:

said first heat exchanger is defined by a domed array of interconnected conduits suspended in said vapor chamber.

8. The floating solar energy conversion and storage apparatus of claim 4, further comprising:

at least one pumping utility shaft extending vertically through said energy conversion chamber and said heat storage chamber, said pumping utility shaft having an interior volume occupied by atmospheric air, said pump being housed in said interior volume.

9. The floating solar energy conversion and storage apparatus of claim 3, where one or more of said heat transfer structures comprises:

a transparent barrier through which the water confined in said energy conversion chamber is directly heated by said solar energy;

a first heat exchanger submerged in the water confined by said energy storage chamber;

a second heat exchanger submerged in the water confined by said heat storage chamber; and

a pump for producing a circulating flow of heat exchange fluid through a closed circuit including said first and second heat exchangers so that solar energy added to said heat exchange fluid in said first heat exchanger is transferred to the water confined in said heat storage chamber when said heat exchange fluid flows through said second heat exchanger.

10. The floating solar energy conversion and storage apparatus of claim 9, where:

the heat exchange fluid circulated through said closed circuit remains in a liquid state at temperatures above its atmospheric boiling point due to water pressure acting on said first and second heat exchangers.

11. The floating solar energy conversion and storage apparatus of claim 9, further comprising:

at least one pumping utility shaft extending vertically through said energy conversion chamber and said heat storage chamber, said pumping utility shaft having an interior volume occupied by atmospheric air, said pump being housed in said interior volume.

12. The floating solar energy conversion and storage apparatus of claim **3**, further comprising:

upper and lower horizontal barriers vertically bounding said heat storage chamber, said upper and lower horizontal barriers each comprising a thermally insulated core sandwiched between first and second layers of water-impermeable material; and

a transparent barrier floating on the water confined in said energy storage chamber, whereby said energy conversion chamber is vertically bounded by said upper horizontal barrier and said transparent barrier.

13. The floating solar energy conversion and storage apparatus of claim **12**, where:

said upper and lower horizontal barriers each comprise a matrix of thermally insulated and water impermeable plates mechanically interlocked with tongue-in-groove couplings.

14. The floating solar energy conversion and storage apparatus of claim **3**, further comprising:

at least one precipitate drain shaft extending vertically through said energy conversion chamber and said heat storage chamber, said precipitate drain shaft being sealed from the water confined in said energy conversion and heat storage chambers, but open to said ambient water beneath said apparatus so that an interior volume of said precipitate drain shaft is occupied by ambient water having a level substantially equal to that of the ambient water in which said apparatus floats.

15. The floating solar energy conversion and storage apparatus of claim **14**, further comprising:

drain means for directing precipitation and waste water to said precipitation drain shaft.

16. The floating solar energy conversion and storage apparatus of claim **14**, further comprising:

an ambient water heat exchanger for chilling said heat exchange fluid;

an elongate flexible ambient water conduit having a first end connected to said ambient water heat exchanger and a second end normally extending downward into said ambient water;

a pump disposed near the second end of said of said flexible ambient water conduit for supplying cold ambient water to said ambient water heat exchanger through said flexible ambient water conduit; and

a tether coupled between the pump and the precipitate drain shaft for drawing the pump up into said precipitate drain shaft for servicing.

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